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ABSTRACT

To prove or disprove the hypothesis that automation and technological change impose increased skill demands on manufacturing and service industries, case studies were made of a bank and a steel and air products company, and of two oil companies, airlines, and electric power companies. The basic conceptual tool used to measure skill demands was the skill profile, a study of the distribution of total manhours required to produce a unit product (or service) along a scale of the least to the most highly skilled labor. The study found that there was little or no net overall tendency for the mean skill level of the workforce to increase with technological change. Small changes in mean skill were largely offset by larger overall productivity increases, and thus, decreases in absolute demand measured in manhours per unit of production for specific skill brackets were more prevalent than increases. Declines in absolute labor demand were greatest for semiskilled workers and the next greatest declines were for laborers. Skilled workers were the least affected. A bibliography, charts, and tables used to develop the skill profiles are appended. (BC)

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THE IMPACT OF TECHNOLOGICAL CHANGE ON MANPOWER AND SKILL DEMAND: CASE-STUDY DATA AND POLICY IMPLICATIONS

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February 1969

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SUMMARY OF OBJECTIVES, METHODOLOGY AND CONCLUSIONS

A. Objectives

Our overall objective was to analyze the manpower and skill impact of technological change. The specific objectives of the present phase were:

1) to apply the skill-profile methodology developed in the course of previously reported pilot investigations to direct labor in further types of technological change, thereby enlarging the available data base and permitting more positive conclusions to be reached;

2) to extend the methodology and/or modify it to obtain parallel data for indirect labor in a subset of the processes studied; and

3) to provide an overview of the manpower demand pattern indicated by the data and draw conclusions relative to manpower policy.

B. Methodology

1) Outline of the "skill profile" method

The basic conceptual tool used is the "skill profile". This is the distribution of total manhours required to produce a unit product (or service) along the scale from least to most highly-skilled labor. A suitable basis for the construction of such skill scales has been established using skill factor scores derived from job evaluation schemes used in most industries.

Unlike headcounts, comparison between skill profiles of newer and older processes permits statistically controlled conclusions to be drawn concerning the impact of technological change on manpower and skill requirements, provided that precautions are taken to control the effects of the following factors: (i) processes to be compared must be matched for the nature and quality of their material inputs and outputs; (ii) they must be in a steady state to avoid contamination by transiently increased manhour and/or skill requirements due to process development, debugging, etc.; (iii) organizational differences between firms must be controlled by replicating each comparison in at least two firms.

Given these controls, paired comparisons of the manpower and skill demand pattern before and after a specific technological advance can be made fully quantitative by the statistical technique of analysis of variance. The effect of central interest in the present study was the (skill level × technology) interaction which was tested for significance against the residual variance in the (skill level × technology × firm) interaction term. When the variance ratio was significant at a selected confidence level, it was inferred that the observed change in skill profile had been caused by the technological change studied.

2) Selection of further direct-labor case studies

The skill profile method which had previously been developed for direct labor only in the pilot investigations of selected technological changes in commercial banks, the steel industry and the aerospace industry, was applied in further direct-labor studies on technological changes in electricity generation, oil refineries, air separation, and airline passenger reservation systems. As before, these cases were each selected as being typical of a large class of similar technological changes in the same and other industries. In each case a fairly recent and pronounced technological advance had become stabilized and was deemed likely to replace the older technology in the near future.

3) Extension of the "skill-profile" method to indirect labor

Preliminary assessment of the applicability of the same method to indirect labor pointed up a number of difficulties which had to be resolved before data collection could begin. The most troublesome of these concerned the identification of the indirect labor force. While direct labor can be identified through its physical proximity to a process, indirect labor is less well defined. A criterion of "process relatedness" was finally adopted, only those functions being included whose withdrawal would cause a rapid decay in process performance. Using this criterion, it was found that indirect labor could be traced and allocated to unit product. This led to the inclusion of maintenance and first level supervision, planning and scheduling, and to the exclusion of technical and research personnel and higher management. In conventional usage these are generally considered overhead functions.

Certain practical difficulties were encountered in acquiring data for indirect labor skill profiles. Records broken down in sufficient detail to allow the accurate allocation of manhours to unit product were only infrequently available, and retrospective breakdowns of data were found liable to introduce significant distortion. Also job evaluation for indirect labor and reconciliation to derive joint skill distributions sometimes presented problems. Nevertheless, the feasibility of applying the skill profile method to indirect labor was established, and complete (direct + indirect labor) profiles were obtained for a sizeable subset of the total case-study complement.

C. Limitations and Sources of Uncertainty

1) Incomplete indirect labor data

By far the largest source of uncertainty encountered in interpreting our overall results arose from the very incomplete coverage of indirect labor which we had been able to acquire within the time and resources available. It has become clear from the studies completed on a pilot basis that direct labor data taken alone yield a misleading picture of the overall manpower and skill impact of a given technological change. It has therefore been necessary to emphasize conclusions based on total data where these were available, even though for lack of replication they were not tested for statistical significance. A very modest further research effort would suffice to round out and substantiate the present conclusions by completing the 18 comparisons undertaken.

2) Variable efficiency of manpower utilization

Certain other disturbing factors could not be fully investigated within the constraints of time and research effort available. Of these the most important was probably the relative effectiveness of manpower utilization across processes and technologies.

In certain cases it was evident that processes were overmanned, in the sense that reducing the complement of some or all skill levels would be likely to cause little or no decline in output. In these cases there is a significant potential for increased labor productivity without further technological change, obtainable by taking up what we have termed "organizational slack". Manpower forecasts predicated on the existing deployment of manhours and skills by process and technology (i.e., based on observed skill profiles) are therefore likely to err on the side of overestimation of future manpower demand. This under-utilization of manpower probably declines with the time for which a given technology level has been established. Since in our cases the newer technology had generally been operating for only a comparatively short time (2-3 years), our estimates of the change in manpower demand might be expected to err on the low side. Despite this factor we observed statistically significant changes in the majority of cases. (See Table 8.8)

3) Lack of comparability of job evaluation scores across industries

In drawing conclusions we needed to standardize the scales used for grouping skill levels and constructing skill profiles. Since, however, every industry uses its own rating scheme, the skill scales used were different for the set of processes studied within each industry. This not only precluded direct cross-industry generalization but called for considerable caution in comparing the sizes of the change in skill level due to technological advance in one process relative to another. What appears as a small change on one skill scale may be equivalent to a much larger shift on another. At a later stage and after some experimentation, we therefore adopted a system of bench marks obtained by comparison of selected job descriptions across industries (see Appendix G). This led to "common denominator" scales making skill profiles broadly comparable. Considerably more effort than we could afford would have been needed to establish a fully standardized universal skill scale.

D. Substantive Conclusions on the Manpower and Skill Impact of Technological Change[*]

1) Technological changes studied

The following cases have been examined:

1. Application of stored-program digital computers, magnetic tape data storage, and machine readable data coding, to commercial data processing

   Process Studied: Check Processing and Account Posting

   Industry: Commercial Banking

   S.I.C. No.: 6022, 6025

2. Replacement of batch by continuous processing of bulk materials with analog automatic control

   Process Studied: Annealing, Galvanizing, and Tinplating Steel Strip

   Industry: Steel

   S.I.C. No.: 3312

3. Application of automatic digital pre-programming and analog automatic control techniques to cutting, shaping, and forming three-dimensional solid components.

   Process Studied: Production of Complex Aircraft Parts

   Industry: Aerospace

   S.I.C. No.: 3722, 3723

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[*] This section integrates the results obtained in the present phase of the research with those obtained earlier (Ref. 1).

4. Application of pre-programmed digital data storage, information processing and transmission to systems meeting geographically widespread demands for service occurring at random in time and space ("random demand real time services")

   Process Studied: Airline Passenger Reservation System

   Industry: Air Transportation

   S.I.C. No.: 4511

5.[*] Application of stored program digital computers to online monitoring and integrated control of continuous production processes previously under conventional (analog) automatic control

   a) Open-loop (computer used for data logging, monitoring, annunciation and performance calculations)

      Process Studied: Electricity Generation (thermal)

      Industry: Electric Utilities

      S.I.C. No.: 4911

   b) Partially closed-loop (computer controls some but not all of the process variables)

      Process Studied: Hydrocarbon Cracking (oil refinery)

      Industry: Oil Industry

      S.I.C. No.: 2911

   c) Fully closed-loop (computer controls all process variables)

      Process Studied: Air Liquefaction and Separation

      Industry: Chemical Industry

      S.I.C. No.: 2813

6. Centralization of manual control over manufacturing and service processes by the use of remote sensors and status indicators, analog data transmission, and remotely actuated control elements

   Process Studied: Electricity Generation (thermal)

   Industry: Electric Utilities

   S.I.C. No.: 4911

Each of these changes may be taken as typical of a fairly wide range of similar technological changes occurring in the same and other industries and services, and together they represent a substantial fraction of current manufacturing and service industry.

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[*] On closer examination of this type of technological change it became clear that we were dealing with three distinct subtypes, and hence that a single sample would not validly represent the population of computer controlled processes.

Six out of the eight types of technological change involved digital computer applications, five (#2, 3, and 5a, b, c) involved analog automatic control, and all involved electrical, pneumatic or or other forms of automatic data storage and transmission. However, none of them involved major increases in the application of mechanical power to replace human muscle power. This concentration on partial automation rather than primary mechanization (advanced in mechanical memory, data transfer and data processing as against further application of mechanical motive power) fairly represents current trends in production and service technology. With the possible exception of agriculture it would have been difficult to find significant case material falling into the class of primary mechanization. However, full automation (leading to unattended operation) was only encountered in one case (5c).

2) Labor Productivity*

a) Direct Labor (18 comparisons covering 8 types of technological change)

Labor productivity increased in 72% of cases, and remained the same in 28%; direct labor productivity was not reduced by any of the technological changes. The largest increase noted was +1,850% of the pre-change productivity, but this was exceptional and normal increases ranged from +25% to +275%. Computer process control was anomalous in that installation of partial computer process control produced no productivity gain, whereas installation of full computer process control (unattended operation) produced a very large gain.

The greatest gains were recorded in those cases where the pre-change technology required the greatest amount of direct human intervention in the process.

b) Total Labor (direct + indirect; 8 comparisons covering 6 types of technological change)

In most cases (88%) inclusion of indirect labor data reduced the productivity gains computed from direct labor alone, and in two types of technological change the result emerged as a small net reduction in labor productivity (-2% to -10%). This dilution was most evident in manufacturing processes with large engineering maintenance requirements. Here the proportion of indirect labor tended to increase with technological change.

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*Primary data on which these conclusions are based is presented in Table 8.1, p. 146.

c) Absolute versus Marginal Labor Productivity

Several sets of data pointed up the need to distinguish between elastic and inelastic components of the labor force on a given process. As a general rule, partially but not fully automated technology, representing the great bulk of post-change processes, shows large marginal but modest absolute labor productivity. However, the one fully automated process studied (#5c; air-separation) showed both large marginal and large absolute productivity increase.

The former case may be described as "labor-static" and is a condition which many important industries have apparently already entered. The latter, "zero-labor," condition still constitutes an insignificantly small, though growing, proportion of actually operating processes in the industrial sector. The rate of spread of labor-static and zero-labor processes warrant special study in relation to future manpower policy.

d) Comparison between Organizations

There was substantial variance between organizations in productivity gains recorded due to identical (or near identical) technological changes. This appeared to be associated mainly with the organizational efficiency with which both older and newer processes were exploited and partly reflects the timing of the change-over in individual organizations, since later adoption of a new technology tends to go with more efficient deployment of the labor force.

3) Changes in skill profile

a) Overall Statistical Significance

The limited amount of indirect-labor data that could be acquired within our resources unfortunately did not permit statistically controlled comparisons between pre-and post-change skill profiles for the total process related work force. However, analysis of variance of direct-labor manhour demands by skill level showed highly significant change of skill profile in 2 of the 7 types and subtypes of technological advance for which analyses could be completed, slightly to moderately significant changes in 3 more, and complete lack of change in the remaining 2. In one of these cases (airline reservations) the low level of confidence was apparently due to large error variance rather than to small changes in skill profile. The skill profile change due to the eighth technological change (computer-controlled air separation) was large, but could not be statistically tested for lack of a second organization in which to replicate the study. This result would almost certainly have been highly significant, so that overall more than 1/3 of the cases yield strong evidence that technology has an impact on skill level.

b) Changes in Mean Skill Level[*]

i) Direct Labor (18 comparisons, 8 types of technological change)

Mean direct labor skill levels increased in 50% of individual comparisons, remained unchanged in 33%, and declined in 17%. Averaging over types of technological change, 4 out of 8 (50%) showed increases, 2 were unchanged, and 1 (12%) showed a decrease. In the remaining case, direct labor had been eliminated, so that the post-change direct-labor skill level did not exist.

The largest increase in skill level (+70%) was recorded in moving from decentralized to centralized control of large process plant. The next largest increase (+20%) occurred in moving from batch to continuous processing of bulk materials. The single small decrease (-6%) was recorded in numerical-control machining. Taking these results together, our direct-labor data thus supports the widely held view that technological advance tends to increase skill demand.

ii) Total Labor (direct + indirect; 5 comparisons covering 5 types of technological change)

The mean post-change skill level computed for the total process-related labor force was increased in 2 out of 5 cases (40%) and reduced in 3 out of 5 (60%). Thus on the (admittedly inadequate[**]) data available the above statement must be reversed, and the final conclusion drawn that on the average technological change tends to decrease the skill demanded of the process-related work force in manufacturing and service industry.

Except in one case (the computerization of check processing in banks) skill increases observed in the direct labor force were largely cancelled out by decreases at indirect labor level. The most striking instance here was centralization of process-control where a direct labor skill level increase averaging +70% was converted to a net decline of -6% by including indirect labor.

It seems that marked increases in overall skill level are associated with technological advance only in the service sector, where indirect labor demands are relatively low. In the manufacturing sector the pattern is rather one of changing the distribution of a more or less constant set of skill levels among the various directly and indirectly process-related roles.

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[*] Data summarized in Table 8.2, p. 160.

[**] Limited resources precluded acquisition of indirect labor data in the remaining 13 cases. Collateral evidence cited in Chapter 8 supports the present conclusion.

c) Impact of Technological Change on Specific Skill Levels*

The changes in productivity and in mean skill level summarized above were the aggregate consequences of a complex pattern of changes in the skill profiles of the various processes. Certain of these more detailed observations are summarized here.

i) Lower skill levels ("unskilled labor")

Only 28% of the pre-change processes required 1/10 or more of their direct labor force at lower skill levels, and the post-change proportion declined to 17%. Put another way, a pre-change average of 7.4% of the labor force classified in lower skill levels was reduced to a post-change average of 4.1%. But in the 8 cases for which indirect labor data was available the net swing appeared much smaller, and there was only a very small (0.1%) and certainly insignificant swing away from lower skill levels. Thus we must conclude that "unskilled" labor continues to account for about 5% of the total process-related labor force despite major technological change in the processes studied.

In absolute terms there was a decrease in lower skill requirements evaluated per unit of product or service.

ii) Medium skill levels ("semiskilled labor")

The processes studied varied widely in the pre-change proportion of middle-level skills required, and showed either no change or a decline in this direct-labor skill component.

However, the addition of indirect labor again diluted the result, for 2 out of 8 (25%) of the comparisons showed post-change increases in the proportion of medium-skilled workers in the labor force, and the overall average result was a quite insignificant decline of -0.6%. Thus we conclude that technological change has on the average no effect on the proportion of medium-level skills in the total process-related work force.

Again, this unchanged proportion is consistent with the fact that due to productivity increase, there was a decline in absolute medium-level skill demand per unit product. A tendency to shift medium-level skill demands from direct into indirect labor accounts for the apparent dilution of the direct-labor observations.

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*Data summarized in Tables 8.3 - 8.6, pp. 161-163.

iii) Higher skill levels ("skilled labor")

The pre-change direct labor demand for higher-level skills varied from 100% to 0% of the labor force. In all cases the post-change demand was increased, generally in amounts exactly matching the decreases observed at medium-skill levels. Here again the inclusion of indirect labor changed the picture very markedly, again leaving little or no change in the proportion of higher-skilled labor, due to technological change for the total process-related work force.

The unchanged proportion of the total labor force at higher-skill levels together with higher productivity reflects a small but definite average reduction in higher-skilled manhours per unit product.

In this case it seems that there has been a tendency to shift highly skilled labor out of the indirect into the direct labor work force. This broadly indicates the use of small, versatile highly skilled direct operating teams instead of larger less skilled crews, with a corresponding reduction in required maintenance and supervisory skills.

4) Impact of technological change on work force educational levels*

With the one exception noted below, the newer technology required a better educated labor force than the old in each case, though differences were small, and the general nature of the process had more effect than the technological change inself.

Specific educational requirements by process are discussed in the relevant chapters and in Section 8.4.

E. Policy Implications

1) Structural unemployment due to technological change, short-term training and retraining

The view, at one time widely expressed, that automation (and by extension technological change in general) cause increased skill demand finds no support in our data. We infer that while structural unemployment (in a carefully defined sense; Chapter 9) may be a real phenomenon, it is not primarily due to technological progress. In the light of this result, active short-term government intervention in the labor market by way of training and retraining schemes designed to bring the supply of skills into line with changed demand, cannot be justified by reference to technologically induced changes on the demand side of the labor market.

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*Data summarized in Table 8.7, p. 168.

2) Long-term training and education for advanced technology

It appears from the pattern of results together with collateral qualitative data obtained from management and previous literature, that the extent and pace of technological change is constrained by manpower supply considerations, rather than the reverse. This implies that promising new industrial and service developments are being postponed or abandoned as infeasible due to (long term) lack of adequate manpower supply. It appears that the most critical shortage is at the level of routine operation and maintenance, where planners cannot count on a continuing supply of skilled personnel familiar with the newer technologies based on analog and digital information, storage, programmed processing and automatic control. Private industry appears unable or unwilling to implement long-term training programs geared to supply this type of worker in sufficient numbers, and promising technological developments are therefore stillborn.

We recommend that consideration should be given to government support for longer-range training programs of apprenticeship type, intended to train labor force entrants in modern production and service technology as applied in specific industries, with the objective of removing manpower supply constraints on the exploitation of high-production technology by providing a steady supply of highly qualified operating and maintenance personnel for potential new processes.

3) Impact of laborstaticity and reduced labor elasticity on full employment policies

Our case-study data, supported by other previously published case studies, indicate that technological advances tend to displace labor from direct production roles. The substitution of indirect for direct labor causes a greater decline in marginal than in average labor requirement per unit product. This in turn causes loss of short-term labor elasticity with respect to demand or production, and in the case of full mechanization with partial automation, the result is laborstaticity, i.e. short-term (1-3 year) unresponsiveness of employment to changes in demand for the product.

Examination of aggregate production/employment series for the industries in question, and for other industries, supports this conclusion and suggests that about 41% of a sample sector of the labor force for which data were readily available (total employment 13.5 M.), was employed in laborstatic industry in the period 1957-63. Laborstaticity appears to be concentrated in consumer nondurable industries and in highly organized bulk services. Little or no data is currently available on the rate of spread of laborstaticity.

This development renders it essential to consider the differential short-term employment impact of increases (or decreases) in demand by specific industrial sector as a function of their technological status, when contemplating the use of fiscal or monetary adjustments intended to secure near-full employment, or control inflation.

Further study of existing data will be required to provide the complete analysis of labor elasticity needed to permit confident prediction of the employment consequences of specific patterns of demand by industry. Longer-range projection of the potential effects of labor-staticity would entail fuller investigation of its underlying technological and organizational causes.

CHAPTER 1: INTRODUCTION AND OUTLINE OF PREVIOUS RESULTS

The research reported below represents an expansion and development of earlier work by the present authors reported in October 1966 under the title "Evaluation of Changes in Skill Profile and Job Content Due to Technological Change: Methodology and Pilot Results from the Banking, Steel and Aerospace Industries" (1). The overall objectives and rationale of the research program were set forth at length in Chapters 1 and 2 of that document and will not be repeated in detail here. However, a brief review of its background and purpose is given for the convenience of the reader unfamiliar with the previous report.

1.1 Structural Unemployment and the Skill Demands of Newer Processes

At the time the research program was initiated (1964), a debate was in progress between the "structural" and "deficient aggregate demand" schools of thought on unemployment. The question was whether the levels of unemployment current at that time, persistently averaging about 6% of the participating labor force and judged unduly high, could be explained entirely by deficiencies in aggregate demand, or whether structural factors in the labor market were also preventing full employment. Proponents of the structuralist view claimed that lack of adequate skills to cope with the (supposedly) increased demands of the newer highly-mechanized and automated technologies was a major new factor preventing normal operation of the labor market, and thus producing persistent underfull employment. It was held that economic policy should take explicit account of this factor. No conclusive evidence was however adduced to confirm the structuralist hypothesis, which perforce remained one of several competing explanations for the aggregate statistical unemployment experience of the nation.

We initially set out to prove (or disprove) the hypothesis that automation and technological change impose increased skill demands on the secondary and tertiary sectors of the economy, that is the manufacturing and service industries labor force. Our pilot results, reported in 1966, were positive, i.e., showed mean increases in skill level, thus supporting the structuralist position, and extended results in the present report confirm and strengthen this outcome.

Meanwhile, the structuralist view has been strongly reinforced both by the subsequent behavior of the U.S. economy, and by the results of direct "subemployment" surveys by the U.S. Department of Labor, Bureau of Labor Statistics.

1.1.1 Unemployment history during the current period of economic growth

National unemployment experience during 1960-1968, graphed in Figure 1.1, strongly indicates the existence of structural factors preventing full employment. The steady downward trend in 1964 and early 1965 was halted around the 3.5-3.8 % level, and despite economic boom conditions accompanied by a degree of inflation, has not broken this barrier. Overall employment has not reached the 98.5-99 % level that would be the characteristic result of strong demand operating on a labor market unconstrained except by local frictional factors, as seen in several European countries. In view of this experience, and after taking due account of the uneven distribution of unemployment over the participating labor force, it seems no longer possible to entertain "deficient aggregate demand" as a complete explanation of persistent unemployment, though aggregate demand is obviously a major influence; some of the hardcore unemployment, affecting perhaps 2 or 3% of the total labor force, must be due to structural factors.

1.1.2 Sub-employment surveys

The result of studies reported by the U.S. Department of Labor in 1967 (2) also provide direct evidence of structural factors and give some indication of their quantitative significance. Examination of 1965-1966 data for the 20 largest U.S. metropolitan areas including about 1 million of the total unemployed, showed wide variations (2.7-6.0 %) in average unemployment rates with the unemployment rate for nonwhites 3 or more times higher than that for whites, and even higher for nonwhite teenagers. These rates had been estimated from sample surveys based on the traditional definition of unemployment as "not working but actively looking for work." Intensive surveys of subemployment made in November 1966 in ten slum areas of eight major cities used a broader definition including those working part-time but looking for full-time work; those earning less than $60.00 per week; those able to work but not actively seeking employment; those (mostly males) "unfound" in these and earlier surveys. The results showed subemployment rates ranging from 24.6% (Roxbury Area, Boston) to 47.4% (East and West Sides, San Antonio), with a mean rate for ten areas of 33.9%. While this indicates the existence of a more serious problem than had been believed to prevail, more important in the present context are the direct explanations given by the unemployed or subemployed for their condition. 43.9% indicated a lack of necessary education, training, skills or experience and 17.4% reported age as a barrier to employment (too young or too old). Employment Service analyses and a Milwaukee study by professional caseworkers and guidance counsellors also point to 30-50 % of the unemployed as being handicapped by lack of skill. Other personal factors found to be significant causes of subemployment were criminal records, health problems and transportation problems; in the November 1966 survey only 17% reported that no jobs were available. A Philadelphia comparison of job vacancies with unemployed points up the situation.

	Slum Unemployed	Citywide Vacancies
White Collar	15%	38%
Craftsmen	15	23
Operatives	11	21
Laborers	26	5
Service	23	13
Never Worked	22	

These results, albeit covering slum areas only, remove all doubt that deficiencies of skill are a major factor responsible for unemployment.

1.1.3 The how and why of structural unemployment

Given this conclusion, the important question remains to which of the many possible structural factors one should assign major responsibility for underemployment. Plausible contenders apart from skill deficiency are geographical immobility; lack of transportation; age distribution and the reluctance of employers to hire older workers; racial discrimination. Skill level shortcomings may be variously associated with inadequate and incompleted education, lack of training or work experience in relation to job demands, or a combination of some or all of these factors.

While each of these and perhaps other structural factors no doubt affects the aggregate statistical situation, previously published discussions (Refs. 3,4) have postulated that the skill deficiency group of factors is the major one at the present time, and assigned the major share of its genesis to progressive technological change causing "phase-out" of previously serviceable general laborer skills.

The data cited above only reveal the importance of skill deficiency as a cause of subemployment, they do not assign reasons for the lack of job opportunities at the unskilled and semi-skilled level. Without further data we cannot confidently link the problem of subemployment in the slums and elsewhere to the characteristics of modern technology and automation, plausible though this inference may seem. The objective of the present research, to obtain direct evidence that the current pattern of technological change entails skill upgrading, therefore takes on new significance as the last link in a chain connecting macroeconomic experience in the national labor market to technological progress in the nation's industries and services. This objective retains its importance and is even reinforced by macroeconomic events that were confidently expected in early 1966 to enforce rejection of the structural hypothesis and with it the problem of changing skill demands.

1.2 Outline Objectives and Results of Phase I

At the outset of the research we undertook an analysis of the methodological prerequisites for acquiring valid evidence of changes in skill demand due to technological change (see Chapter 2 below), concluding that few if any previous observers had succeeded in controlling (in the statistical sense) enough of the potentially disturbing factors to permit them to draw unequivocal conclusions on the impact of technological change on skill demands. As an initial objective we set out to design and conduct pilot case studies that would meet all the requirements determined by our methodological analysis.

More recently we have applied the resulting criteria and data processing procedures to a number of studies reported in the earlier literature. While all of them were deficient in one or more aspect of methodology they nevertheless contained data which could be transformed into the format needed to provide reasonably valid indices of skill impact for various technological changes in different sectors of modern industry (Ref. 9). While these were sometimes at variance with the original authors' conclusions, the general impression derived from some 10 specific cases was of a distinct upward shift in skill level accompanied by a marked increase in productivity (i.e., reduction in total manhours per unit product).

Our own early case studies were selected to represent certain important types of advance in production technology, viz., electronic data processing, flow processing of bulk materials, and numerically controlled machine tools. We were able to overcome several initial difficulties in implementing the necessary statistical controls, and obtained fully quantitative results from two organizations for each of the three process types. Results were expressed as "skill profiles," i.e., labor requirements expressed in manhours per unit product, broken down by skill level. With these data in hand before/after comparisons were drawn on labor productivity, mean skill level, and various other indices regarded as supplementary or subsidiary, viz., mean education level, mean job experience, etc.

As had been expected, the direct labor skill profiles thus derived all showed major reductions in per unit manhour requirement due to technological advance, i.e., increased labor productivity. Mean skill levels were also found to have increased to a modest but statistically significant extent in all cases, except in the last named case (numerically controlled machining) where there was a significant decrease. However there was little sign of an absolute increase in higher-level skill requirements per unit of output in any of the cases.

In three out of four processes studied it was also possible to forecast overall future manpower requirements by skill level for the U.S.A. This was done by using data on the rate of diffusion of each process, combined with our skill profiles. The reader is referred to Reference 1 for a full quantitative statement of the results obtained in case studies A through C.

At the conclusion of the initial phase of the research, therefore, we possessed a clear definitive picture of the pattern of change in skill demands attributable to three major and widely

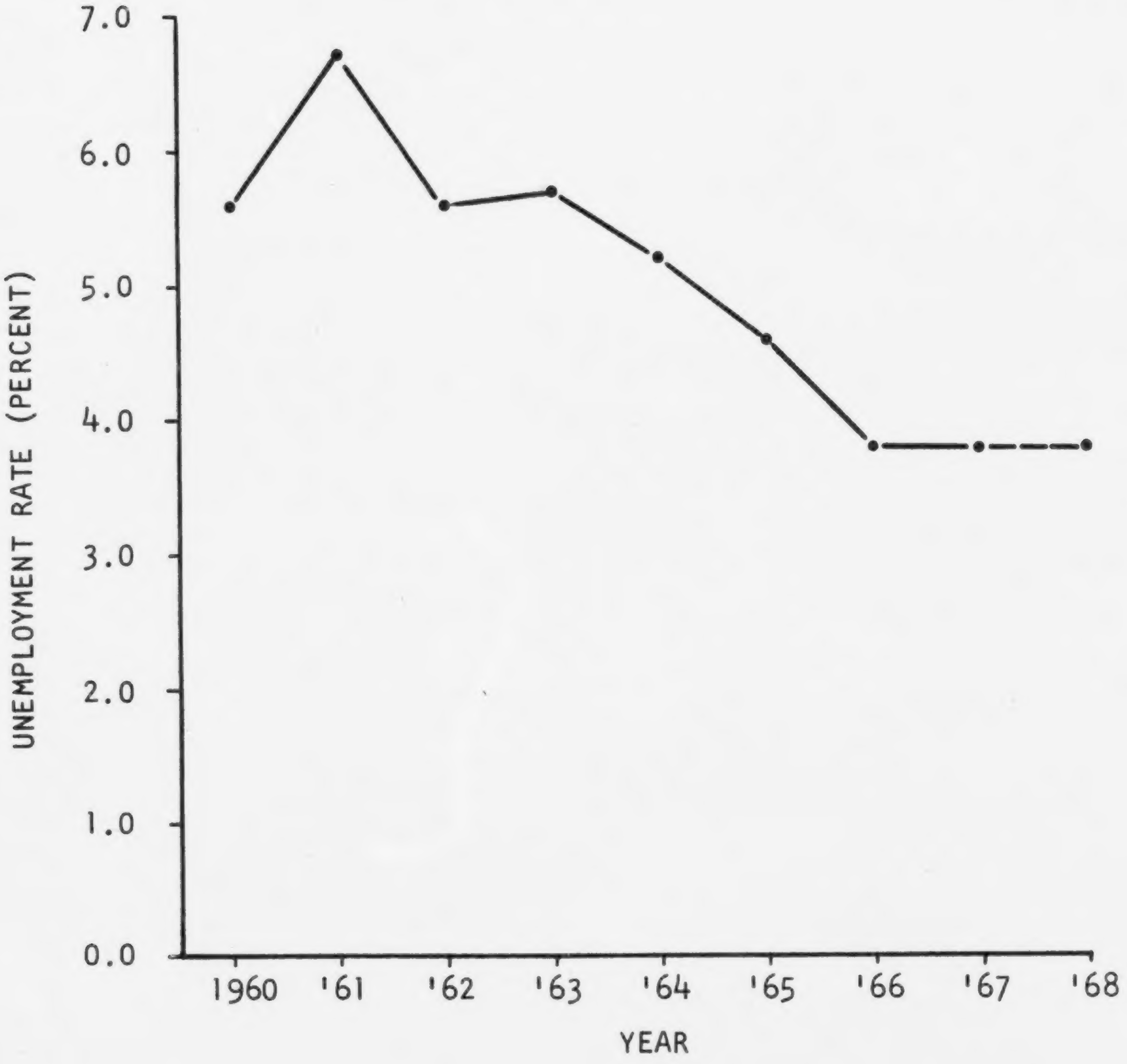

FIGURE 1.1: NATIONAL UNEMPLOYMENT RATES 1960-1968

(Source: Manpower Report of the President, 1968)

NOTE: 1960-1965 are based on people 14 years of age and over, 1966-1968 are based on people 16 years of age and over.

diffused types of technological change, each conclusion being derived from a single well-controlled sample study.

The present phase of the study is concerned with two issues. First we wished to extend the previous results to include indirect labor, thus completing the methodological development, and demonstrating the feasibility of fully quantitative estimates of the manpower impact of technology; and second, we sought to expand the range of technology types studied, to permit more generalized substantive conclusions on the actual historical impact of currently ongoing technological advance.

The first of these issues is covered in Chapters 3 and 4, and the second in Chapters 2 and 5-7. The overall conclusions from the research are presented and discussed in Chapter 8.

CHAPTER 2: PROCESS TYPES, SELECTION OF CASE MATERIAL, AND GENERALIZATION OF RESULTS

2.1 Statistical Basis of the Sampling Procedure

Since the purpose of the research was to assess the impact of technological change on skill levels, education and experience required of the manufacturing (secondary sector) and service (tertiary sector) industry work force, and since we planned to use a microeconomic or case-study approach, the selection of suitable case material was one of our major concerns in this research. In deploying severely limited resources we decided that most information would be gained by exhaustive analysis of the effects of technological change in a number of specific but widely different processes. Each process chosen for study was therefore selected to represent as broad a range of currently ongoing technological advance as possible and hence to permit as wide generalization as possible from the strictly limited number of data points that could be secured.

In statistical terms this procedure is one of estimating the characteristics of a population by inference from a small sample. While in certain cases the proper procedure to secure an unbiased estimate is random sampling, i.e., choosing the case material by means statistically independent of the data obtained, this rule does not appear to apply to the present problem. The reason is that we already possess a great deal of information about the characteristics of the population of processes, enough to classify them into a number of groups on criteria likely to be correlated with the variable under study. Maximum information gain from a given number of case studies therefore calls for sampling as many such groups as possible and restricting the conclusions to the set of groups which have been sampled. As shown by previous field studies the main characteristic of a given process likely to affect the skill impact of technological change is not the industry or service in which it is located, but the nature of the technological change itself. Thus an important preliminary to selecting case material is the setting up of an inventory or taxonomy of process types with a number of instances of each. Ideally, one would then choose at random a single instance from each category, and continue until either resources are exhausted or the observed results showed enough agreement to permit inferring that the variable studied is uncorrelated with the criteria used for setting up the inventory.

There are many types of processes and technological changes that are common to several industries; for example, conventional metal-cutting machine tools and their numerical control successors are used in the aerospace, automobile, heavy and light electrical equipment, and other industries; mechanical and subsequently electronic data processing is used in commercial banks, government, military, insurance, transportation, retail trade. Ideally one would select a random instance of each type from a list of such common cross-industry process types. However, no inventory or taxonomy of processes was initially available to guide the selection, and ensure that it would be truly representative. Since we could not afford to compile such a taxonomy explicitly, we fell back on general knowledge and experience of industry acquired during previous field studies, together with perusal of the current technological literature to guide our selection of case material, with the results given below.

2.2 Selection of Previous Case Studies

The results outlined in Chapter 1 above covered the following three types of advance in industrial and service technology:

Technological Change 1: Application of stored-program digital computers, magnetic tape data storage, and machine readable data coding, to commercial data processing.

Specific Case Studied: Check Processing and Account Posting
Industry: Commercial Banking--S.I.C.* #6022 and 6025
Results apply to similar technological changes (E.D.P. Applications) in:

- Federal and State Government
- Insurance
- Consumer Credit Services
- Retail Trade and Marketing
- Sales Organizations
- Stock Control, Payroll Accounting, Production Planning and Scheduling in Manufacturing Industry
- Military Logistic Services
- Industrial and Scientific Research Organizations
- Health and Welfare Services

Technological Change 2: Replacement of batch by continuous processing of bulk materials, with analog automatic control.

Specific Case Studied: Annealing, Galvanizing, and Tinplating Steel Strip
Industry: Steel--S.I.C. #3312
Results apply to similar technological changes in:

- Nonferrous Metal Industries
- Some Types of Mining

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*Department of Commerce Standard Industrial Classification (1967 Revision).

Paper and Pulp Industry
Chemical Industry
Oil Industry
Printing and Publishing
Cement

Technological Change 3: Application of automatic digital pre-programming and analog automatic control techniques to cutting, shaping and forming three-dimensional solid components.

Specific Case Studied: Production of Complex Aircraft Parts
Industry: Aerospace--S.I.C. #3722-3
Results apply to similar technological changes in:
Automobile Industry
Electrical Equipment Manufacturing
Shipbuilding

On analyzing further instances of these three types of technological advance occuring in the different manufacturing and service sectors of the economy listed above one might plausibly expect to find changes in skill profile and mean skill level similar to those observed in the sample instances and reported below. Our conclusions therefore cover a significantly larger part of the total labor force than might be thought from the limited number of case studies.

This line of thought is not developed in detail here and its definitive implementation will entail a significant effort in identifying and listing similar process types in the different industries and sectors of the economy such as those tentatively listed above. Each of the three studies should be regarded as an indicator for a much larger population or family of related economic activities, in all of which one might expect to find similar changes in skill level and skill profile as technological advance proceeds.

2.3 Selection of Present Case Studies

In order to extend the coverage of technology types as widely as possible on the general sampling basis indicated above, we initially selected three further processes for study in the second phase of the research, but due to difficulty in locating suitable research sites we were forced to abandon one of them (pre-programmed automatic assembly). Only two of the further types of technological advance initially selected were therefore studied, namely:

Technological Change 4: Application of pre-programmed digital data storage, information processing and transmission to systems meeting geographically widespread demands for service occurring at random in time and space ("random-demand real time services").

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Specific Case Studied: Airline Passenger Reservation System
Industry: Air Transportation--S.I.C. #4511
Results apply to similar technological changes in:
- Surface Transportation
- Public Utilities
- Retail Trade and Marketing
- Banking
- Communications
- Health Services
- Brokerage

Technological Change 5: Application of stored program digital computers to online monitoring and integrated control of continuous production processes previously under conventional (analog) automatic control.

On closer examination of this type of technological change it became clear that we were dealing with at least three, and possibly more, distinct sub-types, and hence that a single sample would not validly represent the population of computer-controlled processes. The results of our further investigation, detailed in Chapter 6 below, served to identify these as follows:

5a. Electricity Generating Plant--computer used mainly for data logging, monitoring and annunciation (Electric Utilities, Standard Industrial Classification #4911)

5b. Oil Refinery Catalytic Cracking--computer controls some but not all of the process variables (Oil Industry--S.I.C. #2911)

5c. Air Separation Plant--computer controls all process variables (Chemical Industry--S.I.C. #2813)

Results apply to similar technological changes in:
- Chemicals, Petrochemicals, and Plastics Manufacturing
- Cement
- Pulp and Paper
- Food-Processing
- Iron and Steel
- Shipping

The case study selected for 5a above also afforded an opportunity to secure data on another distinct type of technological advance, and this was added to the list *ex post facto*, viz.

Technological Change 6: Centralization of manual control over manufacturing and service processes by the use of remote sensors and status indicators, analog data transmission, and remotely actuated control elements.

Specific Case Studied: Electricity Generating Plant
Industry: Electric Utility--S.I.C. #4911
Results apply to similar technological changes in:
- Iron and Steel
- Chemical, Petrochemical, and Plastics Manufacturing
- Mining
- Pulp and Paper Industry
- Cement Industry, etc.

2.4. General Nature of Technological Advances Studied

It will be noted that five out of the eight technology types studied (#1, 4 and 5) use digital computers directly, six (#2, 3, 5a, b, c and 6) involve analog automatic control, and *all* of them involve electrical, pneumatic or other forms of automatic data storage and transmission. However, *none* of them involve more than minor increases in the application of mechanical power to replace human muscle power. This concentration on what may be generally characterized as advances in *mechanical memory*, *data transfer and data processing* as against further application of mechanical motive power, was involuntary in the sense that most technological advances now in progress belong to the former class, and it would have been difficult to find significant case material falling into the latter class, with the possible exception of field agriculture where certain field crop harvesting operations are still in process of what may be termed primary mechanization.

To the extent that most technological advances currently in progress, including those studied here, involve mechanization of information processes rather than further applications of mechanical power they all fall under the heading of automation, and form part of the second major phase of the industrial revolution as discussed by Crossman (Refs. 10, 11) among numerous other commentators.

However, as also noted by Crossman, it is mainly information storage, transfer and processing operations directly involved in the production process that are currently being mechanized. Indirect functions such as allocation of work, plant maintenance, planning and scheduling, calibration of instruments, storage and inventory, and development functions such as changes in working methods, plant and system design and redesign, are as yet only being automated in isolated and sporadic fashion. This will be apparent from the later discussion of technology used to perform indirect work (see Chapter 3).

CHAPTER 3: METHODOLOGY: GENERAL AND INDIRECT LABOR

3.1 Formal Statement of Methodology

As noted above, our analysis of deficiencies in the methodology and statistical designs of various earlier microeconomic case studies of the impact of technological advance on skill demands reviewed in Ref. 1, together with re-examination of data gathered in our own earlier qualitative field studies (Refs. 5 and 6), led us at the outset of the research to formulate a list of prerequisites for the acquisition of valid evidence demonstrating changes in skill demand due to technological change. These will now be stated formally.

3.1.1 Controls needed to secure matched-pair comparison

To test the hypothesis that a given technological change involving replacement of an older (lower level) method or process, TL1, by a newer (higher level) one, TL2*, has caused a change (upward or downward) in the skill level of the work force, the following controls must first be established to ensure comparability.

Product

1) TL1 and TL2 must produce essentially the same product or service. Otherwise an observed change in skill level might be due to a change in the product rather than in the process technology.

2) TL1 and TL2 must either operate at the same output level, or their labor requirements must be prorated to the same level. Otherwise observed changes in skill level might be due to different production volumes, rather than to technology level as such (see, e.g., cases J and K below).**

3) Manpower inputs must be specifically linked to tasks performed

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* The development given here assumes that interest centers on technology level. However any other comparison between two (or more) manufacturing and service processes, say two competitors at essentially the same technological level, requires the same set of controls.

**Proration assumes constant elasticity of output with labor input, a condition which often fails in modern large-scale plants. See discussion in Chapter 5 below.

in TL1 and TL2 so that skill demands actually imposed by the respective processes are compared. This requires direct observation or careful inquiry as to the nature of tasks carried out by labor in each case. It further implies that the organizationally-defined "job" concept must be abandoned in favor of the more process-oriented "task". This is because a single job may include tasks related to several different processes, and conversely fractional contributions may be made by several job holders towards meeting the labor requirements of a given process.

Stationarity

4) TL1 and TL2 must both be in a steady state; in particular the newer process TL2 must have passed out of the development and debugging stage characteristic of new technologies, otherwise an observed increase in skill demand might really be due to the (temporary) presence of the extra skilled help which is normally needed in the commissioning phase of a new venture. The older process TL1 may also be disturbed if it is near complete phase-out, due to withdrawal of higher level personnel. While the steady-state condition cannot be precisely defined, in the present study we adopted the criterion that the processes being compared should both have been in continuous operation for two or more years at the time of observation.

Organization

5) TL1 and TL2 must be studied in two or more firms or organizations and the results should agree. Otherwise observed changes in labor requirement and skills might be specific to one organization, and/or be attributable to organizational changes rather than to technology as such (e.g., indirect labor in case J below).

Skill scale

6) The measuring instrument used to assess relative levels of skill, ability and responsibility must be reliable* and free from bias with respect to technology level. A particular danger is that the observer or analyst may be less accustomed to the newer equipment, working methods and unfamiliar environment of TL2, and hence judge the required skills to be more complex. This bias can be reduced or eliminated by securing data from skill analysts known to be equally conversant with TL1 and TL2, which generally restricts choice to personnel in the industry being studied.

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*The term "reliable" is used here in the technical sense defined, for instance, by Guilford (Ref. 7).

3.1.2 Statistical tests to exclude the null hypothesis

Assuming that matched-pair comparability has been established between two (or more) processes in two (or more) organizations, and that the requisite empirical data has been obtained, we may test the hypothesis that there has been a consequent change in skill level. Since there is nearly always some difference, this reduces to the problem of establishing that the observed difference is not due to chance fluctuation.

Testing the null hypothesis

As usual in statistical inference, we proceed to test the null hypothesis, in this case that no skill change has actually occurred. If the probability that the observed data could have been generated by this state of affairs is sufficiently high, we draw negative conclusions. But if it is below, say, $p = 0.1$ (10% significance) we conclude that a change has occurred and we may proceed to estimate its size and direction. This significance test entails forming an estimate of the magnitude of the error variance affecting the result.

In this case the most sensitive method appears to be analysis of variance applied to manhour inputs per unit product. Manpower inputs are readily acquired ratio-scaled data that can be determined to any desired precision. In order to test for a change in skill level we need only to classify these manhour inputs into two or more skill levels, so that a fairly coarse skill scale is acceptable providing it is unbiased with respect to technology.

Assuming that we have manhour data from two (or more) processes (TL1, TL2), from two or more organizations (01, 02), classified into two (or more) skill levels (S1, S2), a three factor analysis of variance is called for, with the following main effects and interactions.

Main Effects

Process (Technology Level)	TL
Skill Level	S
Organization	0

Interactions

Organization X Skill Level	(0 x S)
Process X Organization	(TL x 0)
Process X Skill Level	(TL x S)
Residual	(TL x 0 x S)

We expect the first main effect, which reflects productivity increase resulting from investment in the new technology to show a highly significant F-ratio. The second main effect is determined by our choice of grouping by skill level, that is on the choice of skill scale and grouping intervals used. It is under the analyst's control and ideally its F-ratio should be made insignificantly different from unity, i.e., the skill-scale intervals should be so selected that the manhour inputs are evenly distributed. The third main effect, due to differences between organizations, would ideally also be insignificant, though a modestly significant result does not vitiate the comparison we are interested in.

The first interaction (O × S) will be small if the skill scale is unbiased with respect to organization and if organizational policy on skill allocation is similar. The second interaction (TL × O) measures differences of overall productivity between organizations and will ideally also be small if the organizations invest equally efficiently. The triple interaction term (TL × O × S) measures variations in the double interactions described above and will also generally be small.

Since we cannot meaningfully partition the manhour by skill level data from each process to produce true replication, we are forced to use the variance estimate from this triple interaction to estimate the residual error against which the significance of the main effects and double interactions are tested. If the (O × S) and (TL × O) variance estimates are found insignificant on this basis, they may legitimately be pooled with the (TL × O × S) estimate to improve the residual-error estimate.

Finally the variance estimate derived from the interaction of process type with skill level (TL × S) is the one used to test the major hypothesis. If its F-ratio with the pooled residual-error estimate described above proves significant at some previously chosen (generally low) probability level, we can be sure that there has been a change in skill level genuinely associated with the technological level change from TL1 to TL2.

The sensitivity of this test, that is, how small a change in skill level proves significant, will depend mainly on the amount of extraneous variation found in manhour input between organizations, and particularly on how closely they agree on the allocation of skill levels to tasks in the two processes. Lack of significance does not necessarily imply absence of skill change, but rather that the evidence is insufficient to demonstrate it. Conversely, a high level of significance does not necessarily indicate a major effect, only one which was particularly clearly observed.

3.1.3 Evaluation of the magnitude of change in skill demand

Provided that the analysis of variance described above has demonstrated the existence of a real difference in skill level between TL1 and TL2, we may proceed to evaluate its magnitude by suitable choice of descriptive statistics. However, manpower changes from one process to another are usually complex and we do not expect to be able to find any single perfect descriptor. Further, the relative importance of different statistics will certainly vary according to the scientific or policy question which it is desired to answer at any given time, so we deem it best to present data in several different ways. The following statistics are considered most generally useful.

Percent change in mean skill level and/or mean educational level and/or mean job experience required

Given an ordinal scale on which job and task requirements can be ordered, and corresponding hour inputs per unit product, we may express overall changes in percentage form. Thus if process TL1 requires 20 manhours per unit product at skill level 100 factor points plus 10 manhours at skill level 150, while TL2 requires 10 manhours at skill level 100 plus 8 manhours at skill level 150, the mean skill increase is computed as follows:

$$\text{Mean skill level for TL1} = \left(100 \times \frac{20}{30}\right) + \left(150 \times \frac{10}{30}\right) = 116.7 \text{ points}$$

$$\text{Mean skill level for TL2} = \left(100 \times \frac{10}{18}\right) + \left(150 \times \frac{8}{18}\right) = 122.2 \text{ points}$$

$$\text{Percentage change} = \frac{122.2 - 116.7}{116.7} = \frac{5.5}{116.7} = +\,4.7\% \,.$$

While this statistic certainly reflects the overall skill impact of the change from TL1 to TL2, it must be treated with caution since the skill levels which are combined using manhour data are generally not referred to an absolute datum or benchmark, and hence the same actual change in skill demand may show different percentage results to observers using different skill scales.

The nearest approach to a true ratio scale of skill levels is probably that provided by educational requirements measured in years of school and college. Unfortunately, we have generally found it difficult to establish such levels unequivocally for a given job or task. Similar remarks apply to job experience, and we have thus found it preferable to work with job evaluation data, establishing reference levels and making comparisons as described elsewhere in the report. When carefully applied, these do appear to yield meaningful percent change data when computed as in the above example.

Percentage increase or decrease of labor input in specific skill brackets

For research and policy purposes concerned with such issues as training at specific levels, labor-market analysis, and prediction of skill shortages, it may be more useful to know how much more (or less) manpower will be needed at specific levels than simply how much change there will be in overall skill demands. This statistic may be computed directly from the skill profiles, which are manhour data broken down by skill level. For instance, suppose we are studying the employment of laborers, with skill levels (on a particular job evaluation scale) in the range 80-120 points. Process TL1 requires 13.5 manhours per unit product in this bracket, while Process TL2 requires only 8.7. The impact of the technological change on this skill bracket (assuming constant demand) may immediately be estimated at

$$100 \times \frac{(13.5 - 8.7)}{13.5} = 100 \times \frac{-4.8}{13.5} = 35.5\% \text{ decline} ,$$

the new demand for laborers being 64.5% of the old. This will be independent of what may perhaps be a 15% increase in requirements at skilled craftsman level.

Skill profiles

The most comprehensive way of presenting and evaluating results from which both the above results can be derived, is to give the distribution of required manhour inputs by skill level for each of the processes in question. These distributions are termed "skill profiles" in what follows. They are presented in all cases. In general, we have not found it useful to subdivide into more than about 7 to 10 skill brackets, because at this point chance sampling variations in assignment to brackets become important.

3.2 Pilot Trials of General Methodology--Direct Labor

Following the analysis of methodological requirements which led to the projection of the new methodology formally stated above, the first phase of the research (already reported in Ref. 1) was concerned with testing the feasibility of establishing the controls needed for matched-pair comparisons and with acquiring test batches of the data described above. This was done by two pilot studies of a major technological change, each conducted in a single organization. The cases were selected mainly for ease of access and of data acquisition, and were located in banks (check processing; machine aided manual versus electronic data-processing systems) and steel works (steel finishing; sheet dipping versus continuous strip coating processes). These studies demonstrated that the basic method of matched-pair comparison using skill-profile data was workable, but pointed up three difficulties:

a) Older and newer processes tended not to be found side by side in the same firm for more than brief overlap periods, and firms did not always retain adequately detailed records of operating conditions in superseded processes.

b) Few technological advances could be fully isolated, since managements usually take the opportunity afforded by the introduction of a new process to improve organization, introduce new product lines, change plant layout, etc. It was not always easy to separate these out and record the impact of the technology in a pure state. For instance the adoption of a newer EDP-based check-processing system permitted banks to introduce additional customer services such as automatic loan repayments, a credit card service and so forth. The effects of these additions had to be removed to maintain proper control.

c) The impact of a given technological change on the labor force was found to have no distinct boundaries, effects being traceable with decreasing amplitude in direct labor, indirect labor, overhead functions and thence to quite distant parts of the organization; it was found difficult to delimit the segment of the labor force concerned.

In the two pilot studies these three obstacles were overcome respectively by careful selection of suitable case material, by dissecting out the effort devoted to new ventures and recording only that part of it explicitly concerned with generating the predefined product or service, and by limiting consideration to direct labor.

3.2.1 First series of paired comparisons--direct labor only

Having established the basic feasibility of the method, two further processes where major technological changes had occurred were selected according to the sampling principles laid down in Chapter 2, for study in two firms each. These were in the steel industry (annealing; box versus continuous heat treatment method) and in the traditionally important field of metal processing (machining complex aircraft components from metal castings; conventional versus numerically-controlled machine tools). Also the two original pilot studies were each extended to a second organization thus completing the projected statistical design of the "experiment" for four distinct processes. Data acquired in the eight case studies thus completed was all restricted to direct labor. Care was taken to establish comparability of product across technological levels in each case.

With experience, we found it increasingly easy to acquire the basic quantitative data on process operation, manhour inputs, product specification and output units, skill levels, educational levels and job experience. In later studies most of our time and effort was devoted to study of the process and analysis of task types, to comparative study of older and newer methods, and to assessing the status of the newer methods in relation to competitive processes and projected future technologies, in order to provide insights into the probable diffusion of new technologies through industry.

3.3 Extension to Indirect Labor

3.3.1 Introduction

As noted above, the initial series of eight case studies dealt with changes in skill demand attributable to direct labor only. It was recognized at the time that this would provide only a partial answer to the question of whether overall skill demand tends to increase in newer technologies, and a major goal of the second phase of the research has therefore been to extend the coverage of the new methodology to indirect labor, in order to secure completed comparisons for as many of the previously studied cases as possible. At a methodological level we also wished to develop criteria for deciding how much attention should be devoted to indirect and overhead labor in future studies, concerned either with specific processes or with skill surveys of larger segments of industries and services undergoing technological change.

While the conclusions drawn from the initial studies were confined to direct production labor inputs, a restriction adopted initially to permit completion of a reasonable number of case studies within the research period, this was not a major handicap since in all cases qualitative assessments of the relative weighting of direct and indirect labor (by management informants, and from our own direct observation) indicated that omission of the latter would only affect the results to a minor extent. This claim was based on two distinct arguments, first that indirect labor requirements of each of these processes appeared to represent only a small percentage of the total labor input; and second, that the skill demands for indirect labor were apparently less affected by the technological changes than those for direct labor. These subjective impressions have been borne out in substantive results of research reported below.

While the omission of indirect labor was acceptable in pilot studies, final conclusions on the impact of technology cannot be drawn from direct labor data only. Previous observers have pointed to a general tendency for indirect labor contributions to increase with the level of mechanization, an effect which would bias absolute skill demand estimates downwards if attention were confined to direct labor. In other words, an overall increase in skill demands of newer technologies might well be concentrated in maintenance and other indirect functions. The total skill profiles could be markedly affected by even quite small increases in high-level maintenance skills. More complete data were therefore needed to establish the actual magnitude of this effect in each sample case study.

3.3.2 Methodology for studying indirect-labor skill impact

The first objective of the present research was therefore to establish methods for measuring the skill demands of processes at indirect-labor level. We do not know of any previous studies where this has been done explicitly, and *a fortiori* no one has attempted to assess indirect-labor demands while also controlling for type and volume of product, allocation of tasks to processes, organizational changes, and the other factors listed above.

While the necessary controls had already been established for the four initial pairs of processes, further exploration was needed to establish means of identifying relevant indirect-labor inputs, delimiting the labor force to be considered in before/after comparisons of older and newer processes, measuring per unit manhour inputs, and evaluating skill levels. These methodological issues have been addressed in two pilot case studies which were essentially extensions of the earlier ones, conducted in the banking and steel industries.

Though the methodology finally developed for indirect labor is a little less precise than that for direct labor, it has nevertheless proved feasible to achieve adequate statistical control and precision of measurement permitting fully valid conclusions. The developed methodology has therefore been utilized to complete as many of the further case studies as time and facilities permitted.

3.3.3 Distinction between direct and indirect labor

There is no sharp dividing line between direct, indirect and overhead manhour inputs to manufacturing and service processes, and the boundaries tend to become more blurred with further mechanization and automation.

The definition of direct labor used in Ref. 1 was:

> ... personnel engaged in jobs or tasks making a direct contribution to the conversion of material inputs into products or to the execution of services ordered by customers

and excluded categories were listed as follows:

- personnel wholly employed in maintaining, servicing or repairing the tools or machines used by direct labor to effect conversions on material inputs to products, or required for the processing of data linked to the execution of services;

- supervisory personnel forming part of the line function;

- managerial, staff, engineering or research personnel constituting the organization, coordinating and supportive function;

- purchasing, sales and accounting personnel.

The first of these definitions simply repeats the word "direct" in a slightly more specific context. When conducting deeper investigations into indirect-labor skills, an operational need arose for better criteria to distinguish direct from indirect contributions. For instance, does the operator who actuates a switch causing a conveyor to move materials from one point to another make a "direct" contribution or not? Although his action on the material is quite indirect, the answer is presumably that he does, since without his action production would not proceed. But what about the operator who adjusts the set-point on a flow-controller? In this case the action is indirect, and due to automatic control its omission would not bring the process to a halt, or cause it to produce at unacceptable quality for perhaps several hours. Yet this must a apparently be treated as a direct-labor input since management undoubtedly regards it so. On the other hand, recalibration of an instrument, which may have quite similar effects to changing a set-point, is definitely regarded as an indirect-labor function. It seems that these two cases lie one on each side of the boundary between direct and indirect labor. Hence the proper distinction seems to lie in the timing of the impact which omission of the labor input in question would have on the process.

Accordingly we adopted an operational criterion of "process-relatedness", that is directness of labor involvement, based on how soon withdrawal of the labor input in question would cause a significant drop in quantity, and/or departure from acceptable quality, of the product or service. Direct-labor inputs are those highly "process-related" ones whose omission causes rapid decay of system performance, while indirect-labor inputs are those whose omission will cause deterioration only after a longer period.* The terms "rapidly" and "longer period" were interpreted relative to the inherent timing of the process rather than on an absolute time scale (for further discussion of this point, see Woodward, Reference 12).

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*We considered the possibility of using "half-life" to provide a more fully quantitative index of directness of labor inputs. By analogy with radioactive decay, the half-life of a process is its mean time to failure following total withdrawal of a given section of the work force. The half-life of a manual assembly process would be zero, that of a numerically-controlled machining process (continued)

Our criterion of process-relatedness of tasks and labor inputs was found to agree quite well with those normally used by management, and to produce subjectively good decisions in the numerous marginal cases encountered in the field studies.

3.3.4 Indirect versus overhead labor

Overhead labor may be defined as that part of the labor force which, if withdrawn, would have no effect on the given process (at a technological level) and is hence process unrelated. The sales force obviously falls in this category, as do personnel, industrial relations, etc. Attempts to distinguish between indirect and overhead labor may appear at first sight fruitless since, in the limit, one can regard the whole of an organization as indirectly necessary to support the operation of any single process within it. Again, therefore, the distinction between indirect and overhead labor is one of degree rather than kind. Operationally speaking, we dealt with each case individually by extension of the criterion of process-relatedness (or its inverse) used for distinguishing direct and indirect labor.

Thus, there are many technological jobs and functions associated with a given process which, if not performed, would yet cause no degradation of systems performance over however long a period, given that the system was functioning to specification at a reference time. Instances are programming in EDP systems, product design engineering, and parts programming for numerically-controlled machine tools. As these labor inputs contribute to development of new process or product or to introduction of new organizational activities, they must be regarded as being part of micro-level capital investment directed toward system improvement which is going on continually in most industrial and service organizations. They are considered to fall within the overhead category.

3.3.5 Classification of specific functions

The following classification scheme which was used in the Bureau of Labor Statistics report series "Trends in Manhours per Unit" (Ref. 14) formed the starting point for our allocation of

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about one-half hour, of a modern electricity generating plant several hours, and of a computer-controlled air separation plant several days. The longer the half-life, the less "direct" is the labor in question. In general, maintenance and planning labor exhibit greater half-lives than, for instance, assembly and machining labor. However this degree of quantative precision was deemed unnecessary for our present purpose.

specific functions to direct, indirect and overhead categories.

Direct Labor

- Machine Set Up
- Machining
- Mechanical Working
- Fabrication
- Subassembly
- Assembly
- Finishing
- Painting
- Packing

Indirect Labor

- Maintenance
- Shipping
- Receiving
- Warehousing
- Materials Handling
- Shop Supervision
- Timekeeping
- Inspection
- Production Engineering
- Production Control
- Tools Control
- Materials Control

Overhead Labor

- Developmental Engineering
- Sales
- Company Administration
- Personnel
- Employment Management
- Industrial Relations
- Payroll Records
- Purchasing

Following the above rationale, we preferred to reclassify inspection as direct labor, since if withdrawn this immediately causes a loss of product quality in the sense that the product is no longer known to meet its specifications. Shipping, receiving, warehousing, and materials handling are also direct functions, since the complete production process (including delivery to the consumer) rapidly ceases if they are withdrawn. Production engineering is clearly an overhead function, since it is concerned with development of new products and processes rather than ongoing ones; its cessation has no effect on ongoing production.

Of the remaining indirect functions we have found Maintenance, Shop Supervision, and Production Control (including planning and scheduling) to require significant manpower inputs, while Timekeeping, Tools Control and Materials Control did not make identifiable demands at the process level. Our final listings for indirect and overhead functions therefore read as follows:

Indirect Labor

- Maintenance
- Shop Supervision
- Production Scheduling and Control

- (Timekeeping)
- (Materials Control)
- (Tools Control)

Overhead Labor

- Production Engineering
- Developmental Engineering
- Purchasing
- Sales
- Personnel Administration
- Company Administration
- Employment Management
- Industrial Relations and Salary Administration
- Payroll Records

3.3.6 Allocation of process and proration per unit product

Allocation of labor manhours to specific processes under study is progressively more difficult for direct, indirect and overhead labor since the tasks are successively less closely associated with individual plant and specific production operations. In most cases the activities of a direct labor group are confined to a single plant and/or process, but the activities of indirect labor usually contribute to several different ones, and it is difficult to allocate recorded manhours to a particular one under study. Overhead labor presents the same problem to an even greater extent. The problem of allocating indirect labor manhour inputs to specific processes, and the cognate one of prorating them by product quantity, caused most of the difficulty experienced in acquiring valid data on indirect labor.

Firms and processes differ widely in organization of maintenance effort and recording of work done. In general, each case must be treated on its merits. However, most maintenance, supervision and planning work is usually done by personnel permanently assigned to relatively few processes, and the quantitative uncertainty due to more peripheral and irregular activities is usually smaller than might be anticipated from a mere list of job titles or activities.

3.3.7 Skill level assessment

In most cases the job evaluation schemes set up by management extend or can be extended to shop supervision, maintenance and production planning personnel. We have experienced little difficulty in this area. For further discussion see individual case studies.

3.4 Technology of Maintenance and Production Control

Since each of these studies investigates the impact of a single specified technological change, rather than technological change in general, on labor force skills and manpower requirements, it is necessary to avoid contaminating the main effect by failing to discriminate the effects of distinct technological changes affecting maintenance and other indirect activity which is not involved in the process itself. For instance, there is a tendency to maintain newer instrumentation, automatic control and digital computer systems by detecting and replacing faulty modules rather than by the older method of directly repairing components. This leads to a marked reduction in skilled maintenance manhour requirements per unit product, with a countervailing increase in less skilled labor at the central module repair facility. While this is a significant technological advance in itself, it would be erroneous to treat it as part, for instance, of the installation of an EDP system.

Wherever possible we have therefore ensured that the technology and methods used for indirect tasks were the same before and after the implementation of the major technological change which was the primary focus of the study. Where this was not so, appropriate corrections were made in data reduction, or are pointed out in discussion of specific results.

CHAPTER 4: METHODOLOGY FOR ASSESSING SKILL IMPACT OF TECHNOLOGICAL CHANGE AT INDIRECT LABOR LEVEL: PILOT STUDIES IN DEMAND-DEPOSIT ACCOUNTING AND STEEL-STRIP ANNEALING

4.1 Introduction

The two studies reported in this chapter investigate changes in skill demands at indirect labor level due to technological change. They were extensions of previously conducted studies on direct labor skill demands, intended to test the feasibility of obtaining complete (direct and indirect labor) skill profiles for selected manufacturing and service processes, and of comparing these across technology levels. The general methodology used is set out in Chapter 3 above, and full process descriptions will be found in Appendices I and II, Ref. 1.

The processes studied were:

a) Check processing and account posting for demand-deposit accounting in a multi-branch bank (see Ref. 1, Section 4.1 and Appendix I).

Older Technology (TL1) -- Machine-aided hand process (finally phased out around 1967)
Newer Technology (TL2) -- Electronic data-processing system (installed in 1959)

b) Annealing steel strip, part of the steel-finishing process (see Ref. 1., Section 4.3 and Appendix II).

Older Technology (TL1) -- Box annealing (in current operation)
Newer Technology (TL2) -- Continuous-strip annealing (introduced around 1950)

These two pairs of processes were each studied in a single organization.

The data presented below have been combined with the earlier direct-labor data to provide overall skill-profile comparisons for the two technological changes in question.

4.2 Pilot Study 1: Indirect-Labor Requirements of Check Processing at Two Technological Levels

Identifying Indirect Labor in a Bank

Evidence of a considerable impact of the partial computerization of demand deposit accounting on direct labor employed in processing checks and posting accounts in two multi-branch banks has been presented in a previous report (Ref. 1). In both banks, the introduction some years ago of central electronic data processing installations led to the abandonment throughout most of the network of branch offices, of manual sorting, record keeping and account posting machinery. Some outlying offices, however, had not yet been linked to the central computer installations and it was this circumstance which enabled a comparative study of the manpower and skill requirements of the older and newer information processing technologies. Computerization, it was shown, reduced the direct labor manhours needed to process 1000 checks and deposit slips by just under 50% in Bank A and by some 20% in Bank B; at the same time the mean skill level was higher by 10% in the first, by 16% in the second bank, reflecting the computerized systems' demands for a more skilled direct labor force.

The cooperation of Bank A was subsequently enlisted for a supplementary study of the indirect labor requirements of its manual and computerized systems of check processing and account posting. One component of the indirect labor force that immediately suggested itself was supervision. Beyond this, the application of the criterion of "process-relatedness" pointed at two departments, part of whose functions seemed likely to be performed by indirect labor. They were:

1. Centralized Services--Though mainly concerned with special handling of items (i.e., with extensions of the information processing work done by direct labor), this department also contains a mechanical equipment maintenance section, whose staff of 70 must unquestionably be classified as indirect labor.*

2. The Purchasing, Supplies and Services Department--the main functions of which are described by its title, but which is also involved in the design, format and quality control of all forms including checks used by customers, and in warehousing, record storage, furniture maintenance, etc. Though

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*Bank A's mechanical section does not maintain, repair or service the computers and auxiliary equipment at the EDP installations. This maintenance is done by Field Representatives who are on the computer manufacturer's payroll, but are permanently assigned to each EDP center.

the relevant personnel could be identified, its per unit manhours were far too small to warrant inclusion in the study.

Maintenance and Repair Demands of the Older and Newer Technologies

A fairly precise idea of the effects of technological advances on maintenance activities can be gained by simply surveying the machinery found in a branch office still outside the computerized system and comparing it with the equipment of an EDP center and of a branch office linked to it. This parallels the approach adopted in the direct-labor study where the interest lay in showing how the manpower and skill effects found were related to differences in the operations and methods used in the technologically older and newer plants of the demand-deposit accounting system.

One aspect of the technological changes now penetrating all office work is especially highlighted by the lists shown in Table 4.1: the rapidly progressing mechanization of information processing. Aside from there being more kinds of machines in the newer system, the inventory of machines is much larger. Even leaving the EDP center machines out of account, there has been a marked proliferation of conventional machinery at the EDP-linked branch offices. This is reflected in the absolute number of manhours going into all repair work. In the branch office, representative of the older technology, about 10 man-minutes of repair work are required per week per business machine for a total of about 1-3/4 manhours. In a typical EDP-linked branch office some 11 man-minutes of repairs were needed per week per business machine yielding a total of over 4-3/4 manhours. A ratio of three machines in the newer to every one in the older branch offices is probably not far off the mark.

On the other hand there were no indications of any significant increase in the complexity of conventional machinery, at least insofar as it might make higher demands on repairmen in terms of diagnosing the causes of failure and putting it right.

The electronic data processing and associated equipment at the computer centers is another matter. As the manufacturer's Field Representatives were constantly in attendance throughout each shift, it proved impossible to deduce from observations how much attention the computer equipment demands. Only detailed activity analysis could provide the answer. We therefore included all their time in the totals given below for indirect labor.

Changes in Per Unit Manhour Skill Requirements

The methods employed for determining the per unit manhours of operating supervisors were exactly the same as those used in the direct labor studies previously reported; as supervisors are included in the bank's job evaluation plan, their skill ratings were readily available. Mechanical Maintenance presented more of a problem. As explained in Appendix A, Section 2, different methods had to be devised to arrive at the manhour inputs of the bank's own Mechanical Section on the one hand, and the Manufacturer's Field Representatives on the other; the raw Mechanical Maintenance manhour data will be found in Section 4 of Appendix A. The skill ratings of individual maintenance men included with the manhour data are researchers' estimates.

Table 4.2 sets the total direct and indirect manhours per 1000 items processed by the manual technology (TL1) against the total manhours expended in the application of the computer-centered technology (TL2), the per unit manhours of supervision and maintenance* also being shown separately. As can be seen from the table the indirect labor inputs at TL2 are smaller than at TL1 both absolutely and relatively, due to the evident diminution in the need for per unit supervisory manhours. The relative maintenance requirements have nearly doubled, but as maintenance inputs amount to less than 1% under either technology, this is of no appreciable consequence. In all, the per unit manhours savings attendant upon the introduction of electronic data processing is very close to 50%.

The mean skill levels for the total work force are about 15% higher than for the direct labor force alone at each of the two technology levels. The difference between the mean skill levels at TL1 and TL2, however, is about the same as it was for direct labor alone (Table 4.3), and this despite the very much increased skill demands in the maintenance component of the indirect labor force (+41%); this latter increase had no effect precisely because maintenance manhours account for so small a percentage of the total input. The increased skill level within the maintenance work force is largely the outcome of the inclusion of the computer manufacturer's Field Representatives whose skill was rated extremely high (see Appendix A, Section 4). The changes at each skill level for the composite work force are given in Table 4.4 and in skill profile form in Figure 4.1. For discussion see Section 4.4 below and Chapters 8 and 9.

4.3 Pilot Study 2: Indirect-Labor Requirements of Annealing at Two Technological Levels

Process Description

The processes of Batch and Continuous Annealing have been described in detail in a previous report (Ref. 1) which was exclusively concerned with the direct labor manpower and skill requirements of

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*A more detailed breakdown of Maintenance manhours is given in Table A-1, Appendix A.

TABLE 4.1: OFFICE MACHINERY USED IN THE OLDER AND NEWER CHECK PROCESSING AND ACCOUNT POSTING SYSTEMS

Bank Branch Office Not Attached to EDP Center (TL1)	EDP-linked Branch Office (TL2)
Bookkeeping Machines	Bookkeeping Machines
Adding Machines	Adding Machines
Microfilmers	Microfilmers
Proofing Machines	Proofing Machines
	Dollar Amount Encoders
	Account Number Encoders
	EDP Center (TL2)
	Reader Sorters
	Photoreaders
	Flexowriters
	Tape Drives
	Computers
	Printers
	Adding Machines
	Joggers

Miscellaneous Machines Common to Older and Newer Systems

Typewriters
Postage Meter Machines
Sealers
Check Perforators
Numbering Machines
Electric Time Stamps and Clocks
Coin Counters
Addressograph Machines
Duplicating Machines

TABLE 4.2: DIRECT AND INDIRECT LABOR PER UNIT MANHOURS IN CHECK PROCESSING

	Manhours Per 1000 Items			Manhours as % of Total for Technology Level	
	TL1	TL2	% Change	TL1	TL2
Direct Labor	30.33	15.97	-47.3	87.1	90.2
Indirect Labor	4.51	1.74	-61.4	12.9	9.8
Maintenance	0.18	0.17	- 5.6		0.9
Supervision	4.33	1.57	-63.9		8.9
Other	small	small			
Total	34.84	17.71	-49.1	100.0	100.0

TABLE 4.3: DIRECT AND INDIRECT LABOR MEAN SKILL LEVELS

	Mean Skill Levels		
	TL1	TL2	% Change
Direct Labor	112.3 pts.*	118.2 pts.	+ 9.4
Indirect Labor	187.3 pts.	222.0 pts.	+26.0
Maintenance	176.5	262.0	+41
Supervision	187.7	217.7	+18
Total Work Force	121.9 pts.	128.4 pts.	+ 9.3

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*Base level (minimum skill score) = 52.0 points.

TABLE 4.4: COMPOSITE (DIRECT AND INDIRECT LABOR) SKILL DISTRIBUTIONS FOR MACHINE AIDED CHECK PROCESSING (TL1) AND EDP SYSTEM (TL2)

Organization: Firm A

Process: Check Processing and Account Posting

Product Unit: 1000 Items

Technology (Level 1): Machine-Aided Hand Processing

Technology (Level 2): Computerized Processing

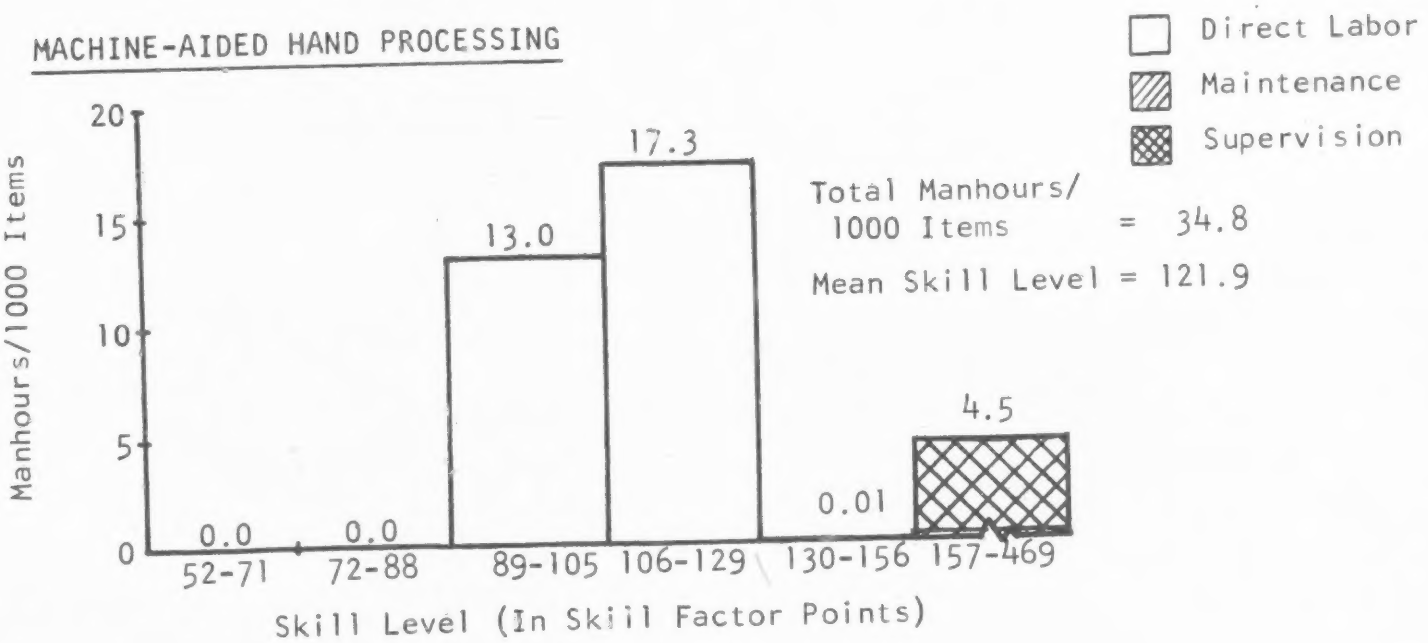
Source of Data: Direct Observation and Company Records

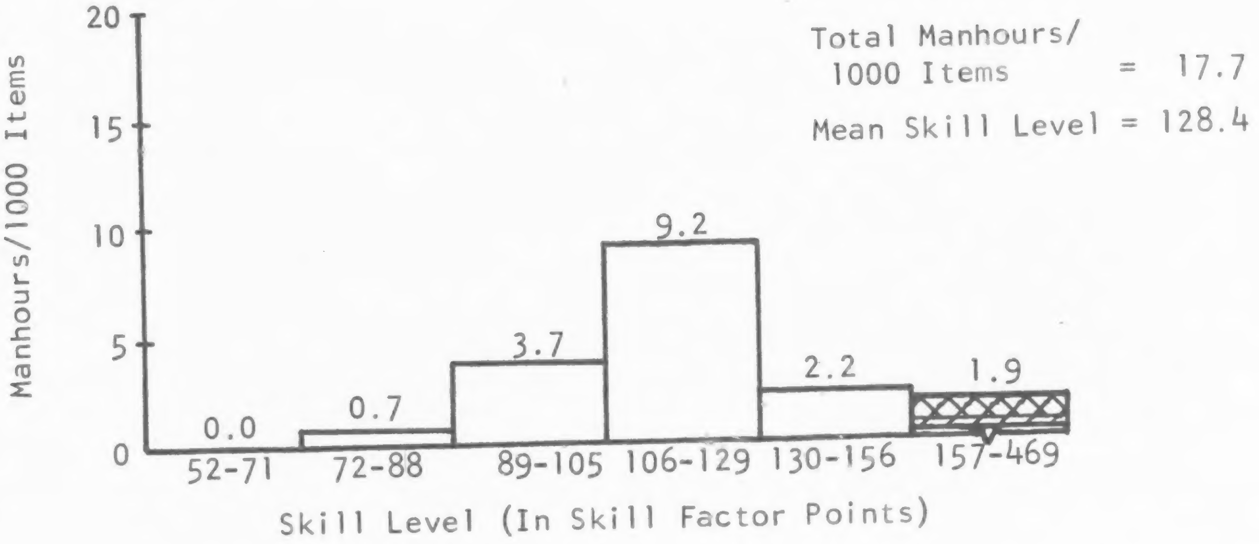
Period: 1965-1966 [Data Acquired - Spring 1967]

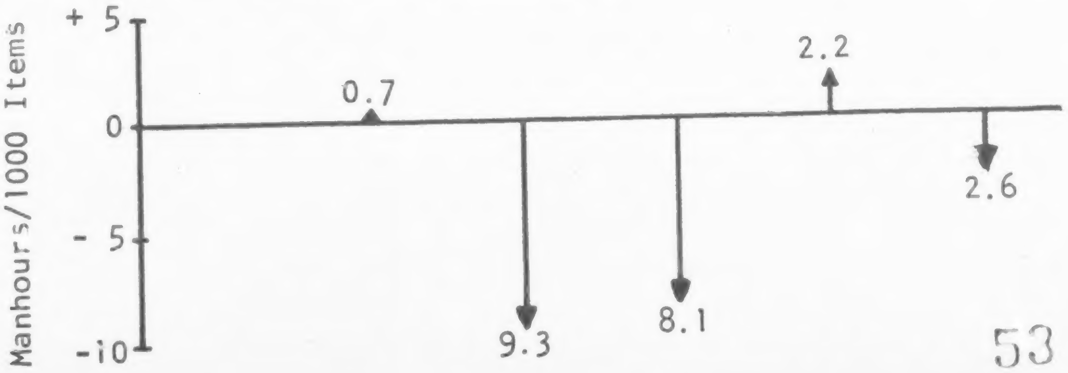
1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 1000 Items			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6										
5	157-	4.5	1.9	- 2.6	12.9	10.7	- 2.2	2	9	+ 7
4	130-156	0.01	2.2	+ 2.2	0.0	12.4	+12.4	1	8	+ 7
Medium 3	106-129	17.3	9.2	- 8.1	49.7	52.0	+ 2.3	1	10	+ 9
2	89-105	13.0	3.7	- 9.3	37.4	20.9	-16.5	3	4	+ 1
Low 1	72- 88	0.0	0.7	+ 0.7	0.0	4.0	+ 4.0	0	1	+ 1
0	52- 71	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	34.8	17.7	-17.1	100.0	100.0	0.0	7	32	+25
	Net Manhour Change -49.1%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	121.9	26.0
Technology (Level 2)	128.4	39.5
Change	+ 6.5 (+9.3%)*	

FIGURE 4.1: COMPOSITE SKILL PROFILES (DIRECT AND INDIRECT LABOR)


MACHINE-AIDED HAND PROCESSING


COMPUTERIZED PROCESSING


CHANGES - OLD TO NEW TECHNOLOGY

these processes. In batch annealing--the older technology heat treatment is applied to steel strip coils stacked on bases by means of a transportable box-shaped furnace which is lowered over the coils and connected to gas and air supply mains. Under the newer technology of continuous annealing, the steel strip is uncoiled and passed through stationary heat treatment furnaces. As the older technology is still in widespread use, the availability of the requisite data was ensured. The batch annealing technology includes a separate cleaning line; on the newer process, strip cleaning is an integral part of the process.

Structure of the Indirect Labor Force

As previously mentioned, selection of the components of the indirect labor force for more detailed study was made on the criterion of "process-relatedness". Discussions with management and examination of the organization charts in Firm C, to which this study was confined, pointed to three groups which conformed to the above criterion:

Operating Supervision

Production Planning

Maintenance

These three groups are distinguished by heavy outlines and by cross-hatching in Figure 4.2. The other functions shown in the figure are staff functions whose work is not wholly confined to annealing, but is distributed over all the steel works' finishing departments: the pipe mill, wire and wire products, sheet finishing, tin finishing and cold reduction. Cold reduction, aside from the two annealing lines, includes a cleaning line, pickling and cold rolling. It was clear from the start that the amount of time the above staff functions devote to each finishing department is negligible to the point of exerting no discernible influence on profiles based on manhours/10 tons.

Further analysis, however, soon showed that production planning and maintenance--the two functions selected for closer study--also have their duties spread over the whole works. Thus Production Planning consists in effect of five distinct successive stages: Order Entry, Steel Providing, Production Scheduling, Warehousing and Shipping (for more detailed descriptions see Appendix B, Section 1). But with the sole exception of Production Scheduling, it is impossible to determine how many manhours out of the total effort going into, say, warehousing goes specifically towards the product being annealed--except that this contribution is exceedingly small. If a reasonably accurate allocation of scheduling manhours to the annealing processes is possible, this is because specific product lines are explicitly assigned to individual schedulers who are responsible for routing the material through them.

Allocating maintenance labor manhours also posed problems. As can be seen by reference to Figure 4.2 the maintenance duties are divided between two independent though loosely connected systems. One of these, assigned maintenance, has a plant-wide complement of about 200 men split into three groups, each permanently located in a particular mill. The cold reduction crew of 6 assigned maintenance men attends to the batch annealing with its associated cleaning line, but also to the cold rolling and pickling lines. Its duties include trouble shooting, inspection and minor day-to-day repairs of the lines while they are running.

Any mill or process can also call on the services of the central maintenance department whose strength is about 285 men. Central maintenance crews may be brought in to reinforce assigned maintenance especially in emergencies. However, the bulk of their time is spent on major, long-time repairs requiring special skills. This is reflected in the organization of the central maintenance department which comprises half a dozen or so specialized shops. The main ones are the Machine Shop which repairs and rehabilitates worn, and builds new, components; the Electrical Shop which repairs and replaces electrical equipment; and the Instrument and Meter Shop which repairs electronic and electrical parts and carries out periodic inspection of these parts throughout the plant. There are also Rigger, Construction, Carpenter, Pipe and Paint Shops. Central maintenance work is requisitioned through job orders sent in by individual units.

At the end of each shift every maintenance man hands in a job card, and these cards were a major source of data in the present research. The job cards of assigned maintenance men contain a record of the production lines serviced during the shift, the number of hours worked on each, as well as the man's badge number; central maintenance men enter the job order number (instead of the production lines serviced), and the hours worked on this order. Job cards are only kept for a relatively short time and for more extensive research it would be necessary to arrange for their retention. This also applies to job orders and requisitions.

Other information needed were the craft of each maintenance man who had worked on the annealing lines, and the skill rating associated with his craft. How the various items of information were combined to derive skill proviles is explained in Appendis B, Section 2.

Manhour allocations were no problem with regard to Operating Supervision, since the first line foremen stay permanently with the direct labor (operating) crews they are in charge of, and the General Foremen were able to estimate how much of their time is spent on each line.

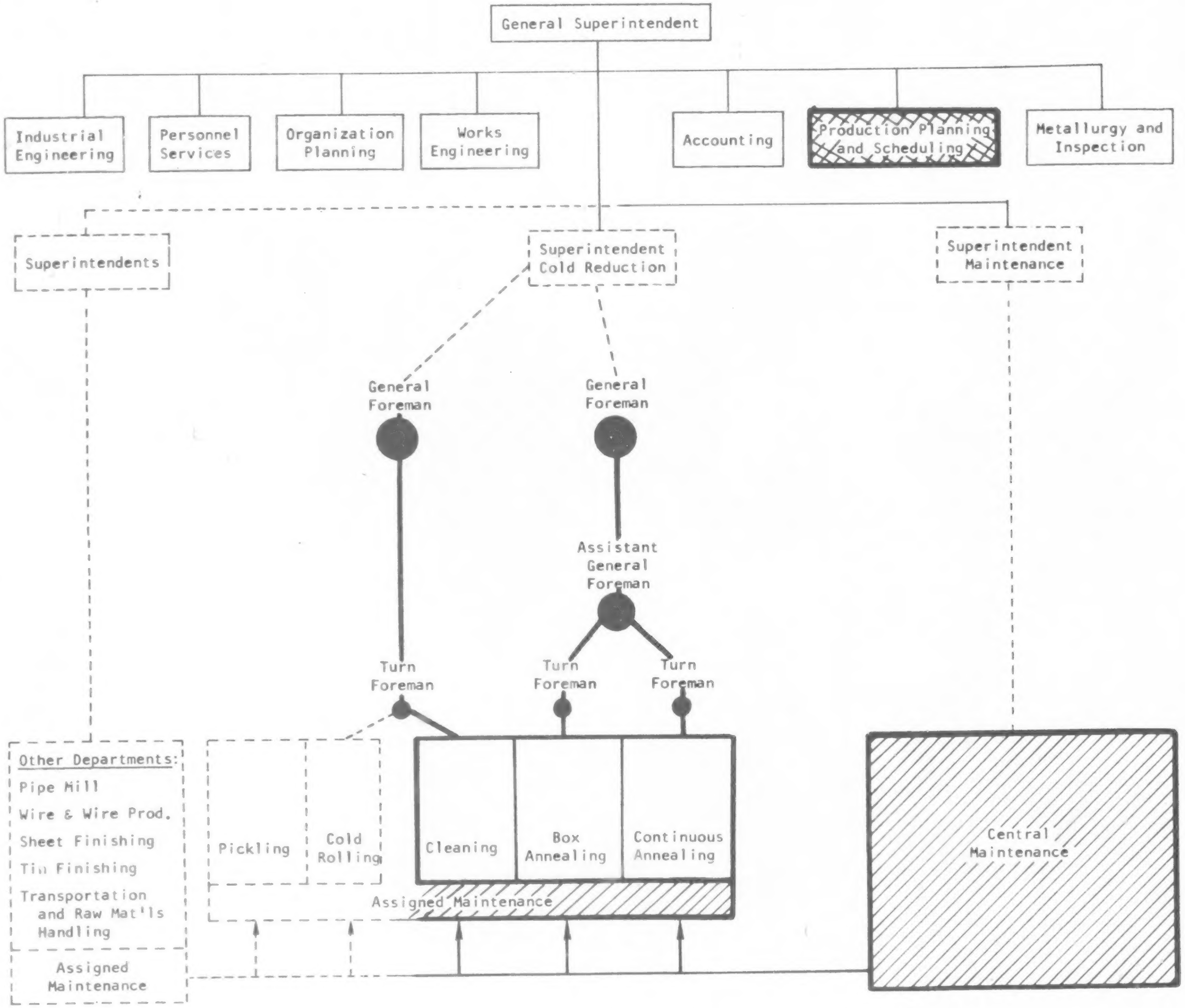

General Superintendent
Industrial Engineering
Personnel Services
Organization Planning
Works Engineering
Accounting
Production Planning and Scheduling
Metallurgy and Inspection
Superintendents
Superintendent Cold Reduction
Superintendent Maintenance
General Foreman
General Foreman
Assistant General Foreman
Turn Foreman
Turn Foreman
Turn Foreman
Other Departments:
Pipe Mill
Wire & Wire Prod.
Sheet Finishing
Tin Finishing
Transportation and Raw Mat'ls Handling
Assigned Maintenance
Pickling
Cold Rolling
Cleaning
Box Annealing
Continuous Annealing
Assigned Maintenance
Central Maintenance

FIGURE 4.2: SCHEMA OF DEPARTMENTAL STRUCTURE OF STEEL WORKS STUDIED

Heavy outlines and/or cross-hatching designate main components of direct and indirect labor force concerned in the annealing processes.

Comparative Operating Supervision Manhours and Skill Levels

As evident from Figure 4.2, the batch annealing and the continuous annealing lines each have their own Turn Foreman, and share a General Foreman and an Assistant General Foreman. The latter two Supervisors each spend about 60% of their time on the continuous, and 40% on the batch annealing, processes. The cleaning line which, as previously pointed out, prepares the strip for batch annealing, and has been considered jointly with this process throughout the present studies, shares a General Foreman and a Turn Foreman with the Cold Rolling mill, enlisting about 1% of the former's and 10-15% of the latter's time. Turn Foremen are one per shift, General Foremen one per day (5 days per week only).

Calculations based on the raw data in Appendix B, Section 3 show that twice as many supervisory manhours were required per unit product heat treated on the continuous (newer technology) line than by the batch or box process including cleaning line. The actual figures were 0.32 manhours, or about 20 man-minutes per 10 tons for continuous, and 0.16, or about 10 man-minutes on batch annealing. The difference is traceable to the fact that, while the continuous line is in perpetual motion and requires fairly frequent attention from supervisory personnel, the coils soaking or cooling under the box furnace require only relatively infrequent and sporadic attention.

As the continuous line makes larger demands than the batch annealing line on the time of the General Foreman and Assistant General Foreman whose estimated skill ratings are higher than those of the Turn Foreman, the mean skill level on this line was somewhat higher (a rise of 0.1, from 8.9 to 9.0).

Comparative Scheduling Manhours and Skill Levels

It should be recalled that out of the five activity phases composing the Production Planning function, Scheduling is the only one related closely enough to individual steel finishing processes for a per unit product manhour allocation to be valid and meaningful. The process-relatedness of scheduling is confirmed by the finding that within Production Planning it was this activity alone in which any changes had to be made when continuous annealing was introduced.

Computations based on a per process breakdown of scheduling office manhours showed that about 0.11 manhours, or 6-7 man-minutes of the assigned schedulers' time, went toward the processing of 10 tons of strip through the continuous annealing line, and about 0.04 manhours, or less than 3 man-minutes, toward the processing of the same amount of strip through the combined cleaning line/box annealing equipment.

The reason why scheduling of material through the continuous line takes up more time lies in the constraints the new technology imposes on routing procedures. To achieve maximum efficiency on the continuous line, for example, the sequence of coil to be fed to the line must be carefully prearranged: their order must be such that wider strip coils always precede narrower strip ones. No such requirement applies to the older annealing process, where coils can be stacked on the same bases virtually without regard to the width of the strip.

Even so the total manhour input was found to be too small to exert a discernible effect on the total per unit manpower requirements.

Comparison of Maintenance Manpower and Skill Requirements

The continuous and box annealing processes are so unlike in every respect that an uninitiated observer would find it hard to believe from inspecting the equipment that they serve essentially the same purpose. As the continuous line is both mechanically and electrically much more complex, it was anticipated that its maintenance requirements would be substantially higher.

The results showed that, while for either process assigned maintenance accounted for over two thirds of the total maintenance labor input, the continuous line required 9% more assigned maintenance and 27.5% more central maintenance manhours per 10 tons of strip than the older batch annealing process including the cleaning line. Moreover, the mean skill level of the central maintenance input into the continuous line was 11% higher than that for the older line.

In all other respects the differences are slight. The overall maintenance labor skill profiles of the two lines are not grossly dissimilar in shape, both being strongly skewed towards the upper end of the skill scale. Separate profiles for the two components of the maintenance force are given in Figures B-3 and B-4 in Appendix B, Section 2; these too are in each case broadly comparable, but they also show clearly that the highest skill inputs are supplied by central maintenance. Averaged over the two annealing lines, the mean skill level of assigned maintenance is 5.8, that for central maintenance 7.7, a difference of over 30%. This however is not at all unexpected, as central maintenance is deliberately conceived as a pool of specialized skills capable of dealing with situations that assigned maintenance crews cannot handle unaided.

Combined Results of Direct and Indirect Labor Studies of Annealing

The final step in the analysis of the manpower and skill requirements of the technologically older and newer steel strip annealing technologies was the aggregation of the data presented both in the previous report and in the immediately preceding sections of this report.

Table 4.5 below summarizes the total manhour inputs contributed to the heat treatment of 10 tons of steel strip by the operators on each of the two processes, and by what has been described as process-related indirect labor: operating supervision and the maintenance and scheduling functions.

TABLE 4.5: SUMMARY OF DIRECT AND INDIRECT LABOR MANHOURS IN THE BATCH (TL1) AND CONTINUOUS (TL2) ANNEALING TECHNOLOGIES

	Manhours Per 10 Tons			Manhours as % of Total for Technology Level	
	Batch TL1	Continuous TL2	% Change	Batch TL1	Continuous TL2
Direct Labor	2.11	1.36	- 35.5	58.5	41.6
Indirect Labor	1.49	1.91	+ 28.2	41.4	58.4
Maintenance	1.29	1.48	+ 14.7	35.9	45.3
Supervision	0.16	0.32	+100	4.5	9.8
Scheduling	0.11	0.11	+175	1.1	3.3
Total	3.60	3.27	- 9.1	100	100

Two findings reflected in this table deserve special note. First, whereas the continuous annealing process requires 35% fewer direct labor manhours per 10 tons than the older (batch) annealing process, this advantage is almost completely lost when indirect labor manhours are taken into account; continuous annealing requires nearly 30% more indirect labor per unit product. In all, the total manhour requirements of continuous annealing are only about 9% less.

Next, there was a remarkable switch in the relative proportion of direct and indirect manhours. On the older process the direct labor manhours accounted for nearly 60%, and the indirect manhours for just over 40% of the total input; on the newer process these percentages were almost exactly reversed. The main component responsible for the reversal is maintenance, which alone contributed more manhours to continuous annealing than direct labor.

The breakdown by skill level of the combined per unit direct/indirect manhours inputs of the two processes being compared is shown in Table 4.7 and Figure 4.3. On the batch annealing process just over one third of the required per unit manhour inputs are at skill levels above 5.5; on the continuous process nearly one half are above this skill level value. The rise of 22.7% in mean skill level, though directly consequent on this shift in the distribution, owes virtually nothing to skill requirement changes in the indirect work force, where the mean rose by only 4.7%, as shown in Table 4.6 below, which summarizes the changes in skill level.

TABLE 4.6: SUMMARY OF DIRECT AND INDIRECT LABOR MEAN SKILL LEVELS; TL1 - BATCH ANNEALING, TL2 - CONTINUOUS PROCESS

	Mean Skill Levels		
	TL1	TL2	% Change
Direct Labor	3.0*	3.7	+23.3
Indirect Labor	6.4	6.7	+ 4.7
Maintenance	6.2	6.5	+4.8
Supervision	8.9	9.0	+1.1
Scheduling	3.0	2.9	-3.3
Total Workforce	4.4	5.4	+22.7

*Base level (minimum skill score) = 0.0

Annealing in the firm studied is thus a case of a process where the comparatively modest productivity gains accruing from a major capital investment in technologically advanced production equipment have been offset to a very considerable degree by the need for specially skilled--and therefore more costly--manpower. (For further discussion see the next section and Chapters 8, 9.)

4.4 Discussion of Results Obtained from Pilot Studies 1 and 2

Check processing and account posting in banks, and annealing of strip in steelworks, were the first processes whose indirect labor requirements were assessed, the objective being to supplement the direct labor comparisons previously reported and thus to provide a more complete account of the manpower effects of technological advance shown in Chapter 2 above. Each of the two processes is representative of a wider family of processes whose technological development has followed, or will follow, a broadly similar course. Demand deposit accounting typifies many cases where electronic data-processing replaces manual methods, while annealing exemplifies the transition from batch to continuous manufacturing processes. The two cases show a marked contrast in impact of technological change at indirect-labor level.

In demand deposit accounting, indirect labor represents only about 10-15% of the total labor force, and most of this is supervision, which is little affected by the technological change. The slight drop in supervisory manhours from 14% to 10% of the corresponding direct labor perhaps indicates a trend to self-supervision on the newer more automatic processes. Maintenance (including external contract labor) represents a very small proportion of the total labor force in both older and newer processes. The greater quantity and complexity of the office machinery employed in the newer system is undoubtedly the main factor accounting for the increase from half to one per cent of the total labor input per unit product.

The skill levels of these two components of indirect labor were, as expected, higher on average than those of direct labor in both cases, and there was a greater increase in skill level with technological change than in the case of direct labor. But because indirect labor is a small proportion of the total, its higher skills affect the overall skill levels and changes to only a small degree. Thus the newer technology requires a skill level on average about 9% higher than the older technology, or a 3% increase over the estimate formed on direct labor alone.

The situation in annealing is altogether different. While the direct labor requirements of the newer (continuous) line are only about two thirds of those of the older (batch) process, indirect labor requirements on this line showed a marked (nearly 50%) increase, reducing the decreases in total labor requirement from older to newer process below 10%. Supervision, at 5 to 10% of direct labor, represents a small part of this while maintenance is the major contributor, with an absolute increase of 15% (0.2 manhours). It requires a higher proportion of the total labor input than direct work on the newer process. This too is a reversal from the older process, where the direct input was greater. Thus the newer process emerges as only marginally (9%) more productive than the old; and since the maintenance force here predominantly requires skill levels well above those of the direct labor force, with pay rates correspondingly higher, it is doubtful that the company has achieved any labor cost reduction at all to offset the initially higher investment for continuous annealing equipment.

From the standpoint of methodology it is clear that omission of the indirect labor contribution to the overall skill profiles caused little bias in the previously reported data for mean skill level from both these cases (Table 4.8). To this extent our previous argument for excluding indirect labor from consideration is corroborated. On the other hand, a sizeable discrepancy appeared in the estimates of changes in per unit labor requirements

TABLE 4.7: COMPOSITE (DIRECT AND INDIRECT LABOR) SKILL DISTRIBUTIONS FOR BATCH (TL1) AND CONTINUOUS (TL2) ANNEALING PROCESSES

Organization: Firm C

Process: Annealing Product Unit: 10 Tons

Technology (Level 1): Box Annealing

Technology (Level 2): Continuous Annealing

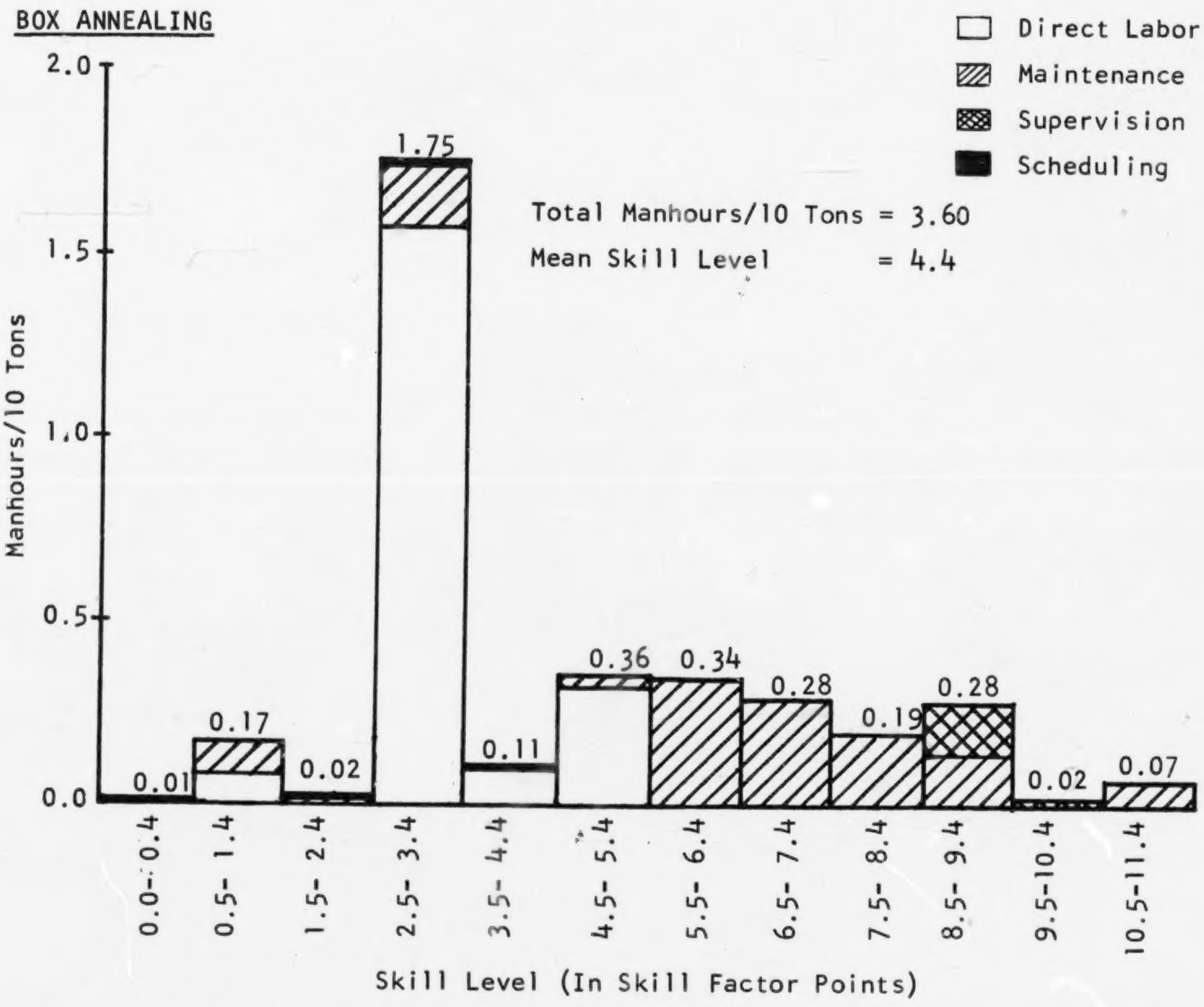
Source of Data: Direct Observation and Company Records

Period: September 1966 [Data Acquired - Winter 1966-1967]

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10 Tons			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
Specialist	10.5-11.4	0.07	0.11	+0.04	1.9	3.3	+1.4	1	1	0
	9.5-10.4	0.02	0.07	+0.05	0.6	2.1	+1.5	2	2	0
	8.5- 9.4	0.28	0.41	+0.13	7.8	12.5	+4.7	5	4	-1
	7.5- 8.4	0.19	0.23	+0.04	5.3	7.0	+1.7	6	8	+2
	6.5- 7.4	0.28	0.27	-0.01	7.8	8.3	+0.5	9	13	+4
High	5.5- 6.4	0.34	0.47	+0.13	9.4	14.4	+5.0	2	1	-1
	4.5- 5.4	0.36	0.27	-0.09	10.0	8.3	-1.7	5	4	-1
Med.	3.5- 4.4	0.11	0.27	+0.16	3.0	8.3	+5.3	4	5	+1
	2.5- 3.4	1.75	1.00	-0.75	48.6	30.6	-18.0	14	9	-5
Low	1.5- 2.4	0.02	0.06	+0.04	0.6	1.8	+1.2	3	4	+1
	0.5- 1.4	0.17	0.10	-0.07	4.7	3.1	-1.6	4	1	-3
	0.0- 0.4	0.01	0.01	0.00	0.3	0.3	0.0	2	1	-1
	Totals	3.60	3.27	-0.33	100.0	100.0	0.0	57	53	-4
	Net Manhour Change -9.2%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	4.4	2.4
Technology (Level 2)	5.4	2.5
Change	+1.0 (+22.7%)	

FIGURE 4.3: COMPOSITE SKILL PROFILES (DIRECT AND INDIRECT LABOR)



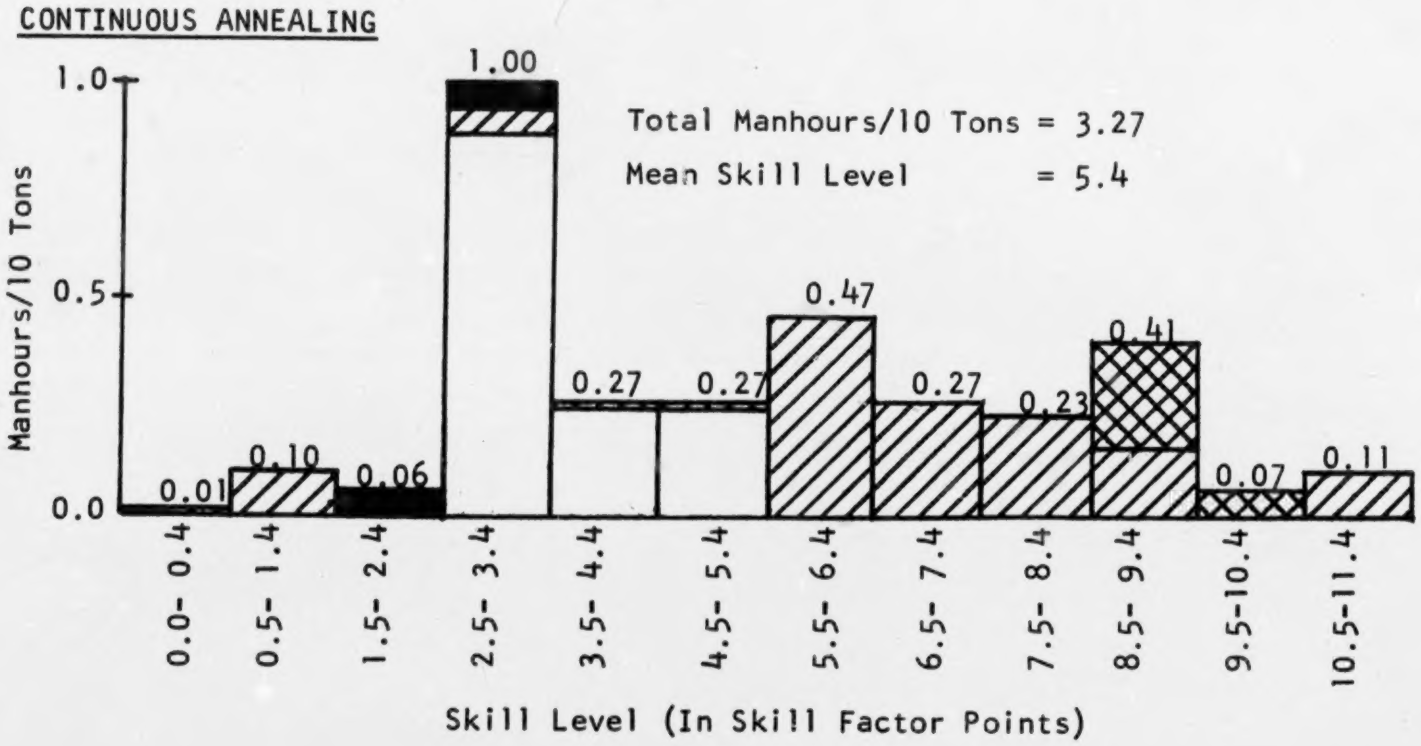


TABLE 4.8: COMPARISON OF RESULTS OBTAINED WITH AND WITHOUT TAKING INDIRECT LABOR INTO ACCOUNT

		Change in Per Unit Labor Requirement Due to Technological Change	Change in Mean Skill Level Due to Technological Change
Check Processing (Firm A)	Direct labor manhours only	down 47.3%	up 9.4%
	Direct and indirect labor manhours	down 49.1%	up 9.3%
	Bias due to omission of indirect labor	2.2% underestimate (4% error)	nil
Annealing (Firm C)	Direct labor manhours only	down 35.5%	up 23.3%
	Direct and indirect labor manhours	down 9.1%	up 22.7%
	Bias due to omission of indirect labor	26.4% underestimate (74% error)	0.6% overestimate (2.6% error)

of the second (steel) process due mainly to increase in indirect activity. This appears to substantiate the view expressed earlier, and by other writers, that automation of manufacturing processes is associated with increase in proportionate weighting of indirect labor.

However, comparison with the results of subsequent studies detailed below suggests that the technological change from batch to continuous processing of materials may be atypical of the general run of technological advances, showing a larger than normal increase in indirect labor requirements.

The pilot results also indicate that supervision and maintenance between them account for the bulk of the indirect labor input, and hence suggest that further studies should include these particular components of the labor force in order to ensure reliable results. However, supervision may be excluded with little risk of serious bias since it tends to be a fixed percentage of direct labor.

CHAPTER 5: IMPACT OF REMOTE CONTROL CENTRALIZATION ON SKILL DEMANDS IN ELECTRIC POWER GENERATION (DIRECT AND INDIRECT LABOR)

5.1 Introduction

Background and results of a skill profile comparison between decentralized and centralized control systems for electric power generation are presented in this chapter. This particular type of technological change was not included in the original list drawn up in the planning phase of the project. However, an unexpected opportunity arose to assess its impact in the two electric utility firms selected originally for investigation of the effects of introducing process control computers. Following the format adopted in our earlier report (Ref. 1) we present first a general and technological description of the process, then a description of the technological advance being studied, followed by results and discussion of our inquiry into consequent changes in manpower requirements and skill profiles.

The technological advance in question consists in the centralization of previously dispersed control functions, permitting the whole operating crew to be located together in central control rooms with consequent improvement in ability to exchange tasks and functions. This change is made feasible by advances in automatic and remote control technology and instrumentation, but has a marked effect on work organization and operator skill requirements. Its skill impact is therefore of general interest.

One of the two firms where these studies were carried out also agreed to an extension to indirect labor. It is thus possible to present an overall estimate of the manpower and skill effects of centralization. This permits a distinction to be drawn between the effects of centralization and computerization, two technological advances which are commonly confused.

5.2 Decentralized and Centralized Control in Electric Power Generation

Recent Trends in Power Generation Technology

Though the modern power plant is impressive in the bulk and complexity of its equipment, the process of generating electricity is based on the simple principle that the rotation of a magnet within wire coils induces movement of the electrons in the wire; the propagation of this movement along the wire constitutes the flow of electric current. In a power plant the magnet and wire coils are encased, forming a generator. The rotating magnet which is the core of the generator is extended into a shaft actuated by a turbine, consisting of rows of circular frames each holding hundreds of small blades set at an angle to the frame. By directing jets of steam or streams of water against the blades, the frames are made to revolve thus spinning the generator shaft.

The use of steam or water for driving turbines underlies the distinction between steam power generation, (accounting for more than 4/5 of total U.S. electricity production), and hydroelectric generation. The present studies were conducted throughout in steam power plants which utilize oil and/or natural gas as fuel for producing steam; these conventional fuels have recently started to be displaced by nuclear energy.

In power plants built before the late 1940's, steam produced in several boilers is fed to a common supply point which in turn distributes it to individual turbines; the supply point is known as a "header". The header system has the merit that one or more boilers can be laid off for overhaul or repair without shutdown of the generators. With boilers of older construction, typically breaking down within one to four months from the date of repair or overhaul, this was a major consideration.

A breakthrough in boiler construction which raised their reliability to near 100%, led to a new conception in the design of power plants as a whole. Capable of operating at very substantially higher pressures and temperatures, and with a much greater steam output capacity, the new type of boiler can reportedly be operated without overhaul for periods of up to four years. The new, large, high capacity boilers also call for less initial capital outlay than several small boilers. Accordingly, the header system has given way to the one boiler/one turbine/one generator "unit" system. Improvements in turbine and generator design allow the greatly increased steam output from the new boilers to be translated into higher power outputs. Some of the most recently installed single units have three or more times the capacity of some of the entire older power plants.

These developments in operating equipment have been paralleled by the concentration of control functions in central control rooms, allowing a greater measure of coordination both within the plant and between the plant and dispatch function which mediates between customer demand and the network of power plants. Unlike other products, the power plant output cannot be stored and the whole network, as well as individual plants within it, must be capable of rapidly responding to short term fluctuations in demand. Because of this, and because of the disruptive effects power failures have on an economy which has grown more and more dependent on electric power availability, the problem of maintaining and improving control over production is one of the standing preoccupations of the industry.

Even in the oldest plants many of the process variables are regulated by local automatic control loops; these are linked to control boards mounted close to the operating equipment permitting manual override. With centralization, the control boards were retained as relay boards and important instrument measurements are transmitted to new integrated panels in the central control room. Pneumatically actuated valves were installed to permit remote manual control from the central control room to be substituted for local automatic control whenever necessary. Conversion from the "header" to the consolidated one boiler/one turbine/one generator "unit" system facilitated implementation of centralized control.

Present practice favors the use of one central control room to every two "units", and the allocation of a complete crew to it. To link four or more units to a single control room, apart from presenting technical difficulties, is considered by some engineers to place an excessive load on the crews and to endanger both personnel and equipment.

As of March 1965, 81 digital process control computers were in use in steam electric power plants across the nation (Ref. 13). Increased safety, improvement in continuity of service, and reduction in fuel, operating and maintenance costs are usually given as the main reasons for the installation of process control computers. However, the amount of control exercised by the computers that were actually installed in generating plants of most of the larger utility companies in the U.S. falls far short of being either complete or continuous. Closed-loop operation is confined to start-ups and shutdowns, which are relatively infrequent events, while in the day to day operation of power plants the computer is employed mainly to warn operators of unusual plant conditions. Otherwise the major portion of computer capacity is devoted to data-logging and to performance calculations. All in all, the impact of process computers to date has been small.

The overall impression gained by the investigators in the firms studied is of an industry in a state of consolidation of recent technological advances: even with the growing use of nuclear energy, the operational and organizational pattern now established in the newer plants is not expected to change, except in relatively minor respects.

More detailed descriptions of the steam electric power generation process, and of some of the more important control aspects of this process, will be found in Appendix C, Section 2.

Definition of Technology Levels

Electric power plants were originally selected for study as being typical of industrial processes where conventional (analog) automatic control was being replaced by more or less direct computer control. During our preliminary inquiries it became evident that centralization of control is a necessary prerequisite to computerization, and generally antedates it by some years. While in certain cases the two developments tend to merge, they represent distinct stages of technological progress, centralized non-computerized control being the typical system in use in process plant in the recent past. Put another way, the decision to centralize control must precede the decision to computerize, but the former does not imply the latter. However, sophisticated analog automatic control technology, the possession of reliable remote actuated control devices, and reliable remote reading instrumentation are prerequisite to centralization. Once these technological advances are consolidated in a given process industry, centralization is a natural, indeed inevitable, step to take. Therefore centralization really implies arrival at an advanced technological level in automatic control and instrumentation.

Some electricity generating concerns have decided that computerization does not currently repay its cost, and for these cases centralized automatic/manual control is the standard current technology.

In the light of the above considerations, it was decided to investigate and develop skill profiles for three technology levels, defined respectively as non-centralized (TL1), centralized (TL2) and centralized/computerized (TL3) process control. Plants operating at each of these three levels were found in both cooperating utilities, which are identified by the code letters J and K.

The analysis in this chapter will be confined to comparisons between the non-centralized and centralized control technologies; both modes of control can also be viewed as forms of semi-automatic control. Comparisons between the centralized and centralized/computerized control modes are included in the next chapter, where they figure alongside other studies of the effects on manpower and skill requirements of manual and computer control respectively.

The comparison was unfortunately complicated in some of the power plant case studies by differences in control technology coinciding with differences in plant capacity. Where this occurs it is impossible to determine whether a given decrease in manhours per unit output (10^6 kwhr) should be ascribed to altered control methods or equipment or merely to a fortuitous increase in capacity. To escape from this dilemma the manhours expanded in toto and at each skill level were related to plant operating hour as well as to unit output. Any manhour changes per unit output are effectively net changes, whereas changes per plant operating hour result exclusively from changed methods of operation and control.

Description of Non-Centralized and Centralized Plants

It would have been desirable to select, at least in each company, plants identical in every respect except for the independent variable of non-centralized and centralized control. As evident from the table following, this aim was only partially achieved.

On a priori grounds it further seemed particularly important to find in both companies plants matched in generating capacity and in the number of boilers and turbine-generators. Plants J1 and J2a met this criterion perfectly, while Plants K1 and K2, though approximately equal as to number of pieces of operating equipment, had very different capacities. It was this difference which compelled a supplementary analysis of skill profiles related to plant operating hours.

TABLE 5.1: CHARACTERISTICS OF NON-CENTRALLY (TL1) AND CENTRALLY (TL2) CONTROLLED POWER PLANTS

Plant Code Name	J1	J2a	K1	K2
Built In	1949	1954 (Modernized)	1930	1961
Control System (Technology Level)	Non-Centralized (TL1)	Centralized (TL2)	Non-Centralized (TL1)	Centralized (TL2)
Main Plant Design Features	Header System with Single Stage, Single Flow, Turbine Units	As J1	Header System with Vertical, Compound, Single-Flow Turbine Units	Unit System with Cross-Compound, Four Flow, Turbine Units
Generating Capacity	300 MW	300 MW	122 MW	660 MW
Number of Boilers	7	7	3	2
Number of Turbine-Generators	4	4	2	2
Steam Generating Capacity Per Boiler	400,000 lb/hr	400,000 lb/hr	500,000 lb/hr	2,160,000 lb/hr
Capacity of Each Turbine-Generator	75 MW	75 MW	61 MW	330 MW

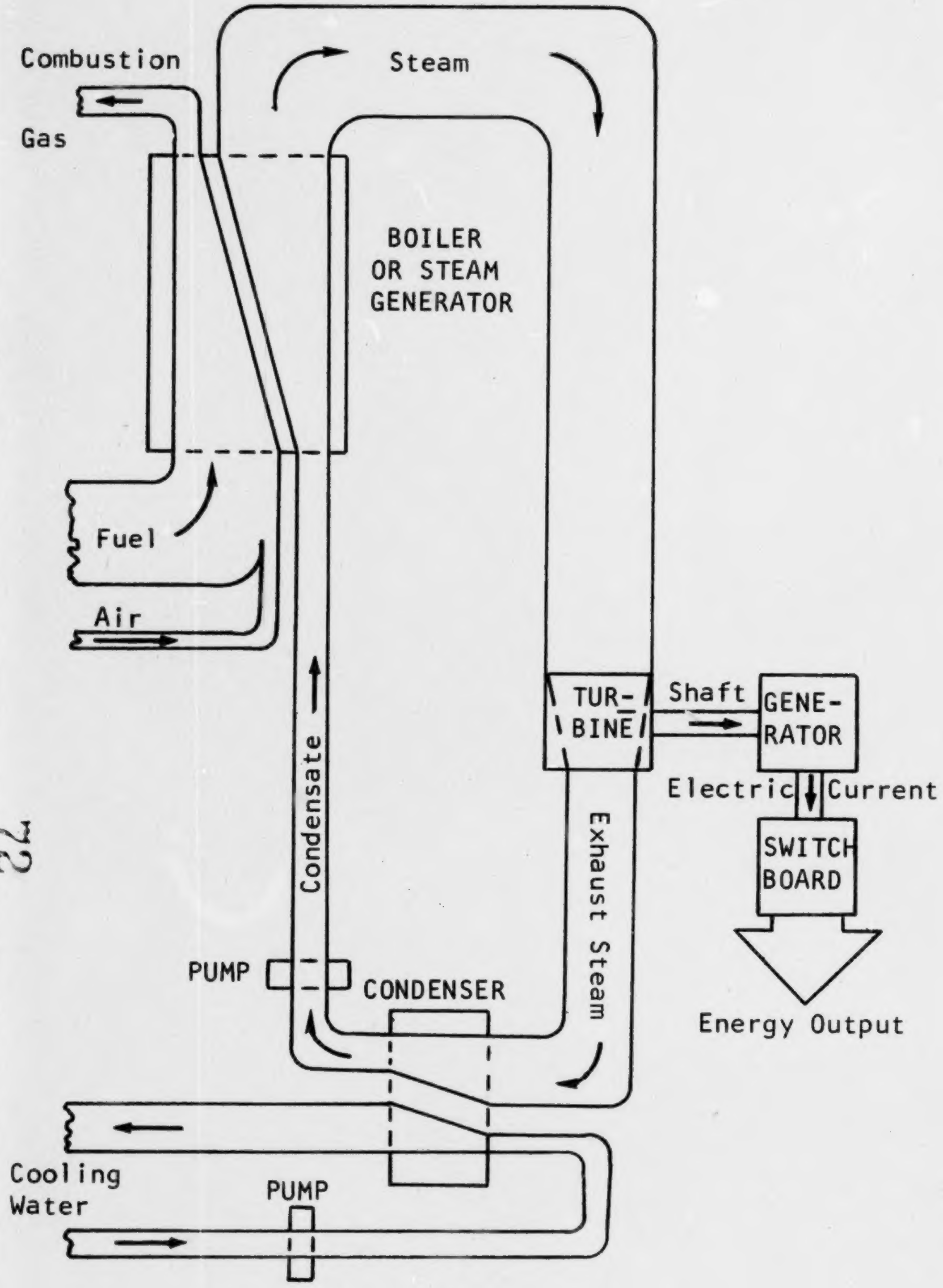
With regard to the independent variable, plants J1 and K1 are typical examples of decentralized control which was general to all power plants built in the 1930's and 1940's. Perhaps the term "dispersed" control would have been more descriptive of the older system then "non-centralized". Individual operators were stationed at the boilers, the turbines, the boiler feed pumps, and at various auxiliary equipment locations. The control boards situated in immediate proximity to each piece of equipment only displayed status information about this operating equipment, coordination of activities being maintained through voice communication. The operators, though thoroughly familiar with the equipment under their immediate control, had only very superficial notions about other operating equipment or the functioning of the system as a whole. Rotation within operating crews was apparently not widely practised. A simplified generalized representation of the manning scheme in a non-centralized plant is shown in Figure 5.1. More detailed flow diagrams and manning schemes for the two plants are included in Appendix C, Figures C6 and C10.

Of the two plants representative of the centralized control technology, plant J2a is physically identical with plant J1; a central control room was set up in 1954 and all the control gear inside it is simply a duplicate version of the remotely located panels (which were left in situ). Plant K2 on the other hand was from the start conceived as a one boiler/one turbine/one generator "unit" system, with a central control room as an integral part of the system. The steam-generating capacity of its two boilers (Table 5.1), which produce over four times as much steam as did the two boilers in plant K1, is the main factor responsible for its much larger overall power generating capacity, which compares favorably with the most up-to-data plants in the U.S.

Some of the technical aspects of centralized control have been outlined in the introductory section, and further explanations are given in Appendix C, which also contains separate flow diagrams of plants J2a and K2. A graphic overall impression of the manning of centralized plants is conveyed by the simplified diagram in Figure 5.2.

5.3 Manpower and Skill Impact of Centralization

To characterize the changes in the work system brought about by the centralization of control functions, it is insufficient to refer merely to the concentration of previously dispersed operators within the walls of a central control room, or to the reduction in the size of the working crews. Each operator in the central room must now be "polyvalent" in the sense that he has to understand and be able to deal with the exigencies of the whole system. For this he needs initially a much broader conception of the system, and must in the course of his experience build up a much more extensive and diversified schema of its functioning. On top of this he must sustain a substantially higher level of vigilance. He is constantly reminded of the potentially catastrophic consequences of failure, and encouraged to broaden his theoretical knowledge. More and more


Combustion
Gas
Steam
BOILER
OR STEAM
GENERATOR
Fuel
Air
TUR-
BINE
Shaft
GENE-
RATOR
Electric
Current
SWITCH
BOARD
Energy Output
Condensate
Exhaust Steam
PUMP
CONDENSER
Cooling
Water
PUMP

Control Locations	Operators	
	Study J1	Study K1
At Steam Generators (Furnaces and Boilers)	1st Boiler Operator Boiler Operator	H.P. Fireman
At Turbine-Generator	1st Turbine Operator Turbine Operator	Turbine Tender
In Switching Control Room	Switchboard Operator - Steam	1st Operator, Switching
In Auxiliary Equipment Area (Pumps, Heaters, etc.)	1st Auxiliary Operator 2nd Auxiliary Operator	Oiler H.P. Fireman Boiler Feedpumpman Shift Helper

FIGURE 5.1: NON-CENTRALLY CONTROLLED POWER PLANT (TL1)

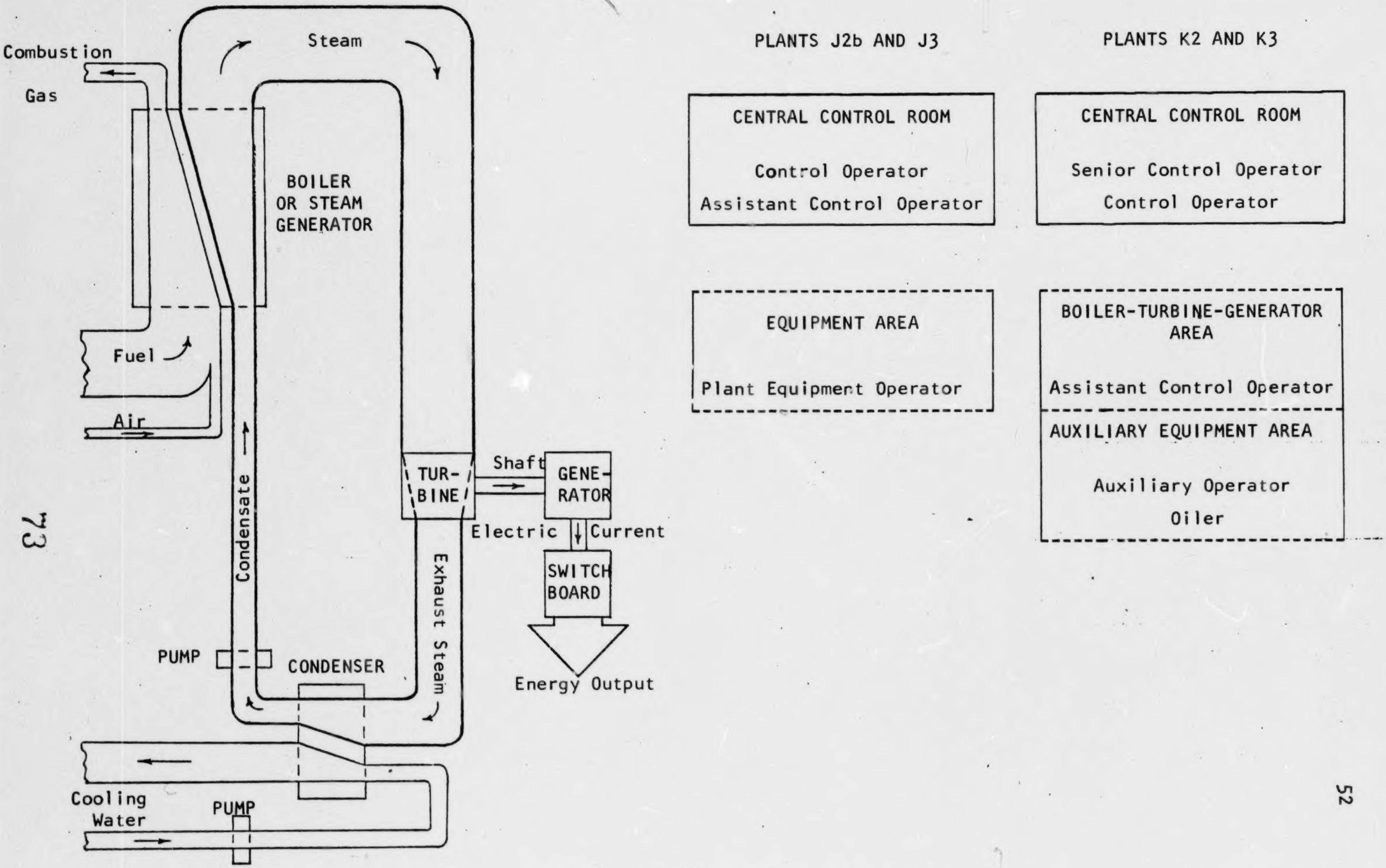

Combustion
Gas
Steam
BOILER
OR STEAM
GENERATOR
Fuel
Air
Condensate
PUMP
CONDENSER
Exhaust Steam
Cooling
Water
PUMP
TUR-
BINE
Shaft
GENE-
RATOR
Electric
Current
SWITCH
BOARD
Energy Output
PLANTS J2b AND J3
CENTRAL CONTROL ROOM
Control Operator
Assistant Control Operator
EQUIPMENT AREA
Plant Equipment Operator
PLANTS K2 AND K3
CENTRAL CONTROL ROOM
Senior Control Operator
Control Operator
BOILER-TURBINE-GENERATOR
AREA
Assistant Control Operator
AUXILIARY EQUIPMENT AREA
Auxiliary Operator
Oiler

FIGURE 5.2: CENTRALLY CONTROLLED POWER PLANT (TL2)

managements of electrical utilities tend to view the training of their operators not as a relatively brief episode with a definite terminal point but rather as a continuing process. This should be borne in mind in assessing the quantitative shifts in the skill distributions.

Changes in Manhour Requirements*

As the output capacity of Plant J1 remained the same after its conversion into centrally controlled Plant J2a, the percentage decrease in the total manhour inputs is the same whether unit product (Table 5.2a and Figure 5.3a) or plant operating hour (Table 5.2b and Figure 5.3b) is taken as basis for computation. The decrease is close to 50%, and is strikingly similar to the decrease recorded for the two plants in Firm K when considered on the per plant operating basis (Table 5.3b and Figure 5.4b). These manhour reductions are ascribable entirely to the change in the control technology used, which is evidently capable of halving the manpower requirements of a generating plant.

This certainly amounts to a marked improvement in labor utilization. However, where the centralized control technology coincides with the installation of higher output capacity equipment, as happened in Plant K2, the per unit kwhr manhour reductions are much greater. To produce a kwhr in Plant K2 required less than 10% of the manhours needed in Plant K1.

That the newer control technologies demand more skill on the part of the operating crews is shown unambiguously by the very large increases in mean skill levels from TL1 to TL2 and also by the shifts in the distribution which have radically changed the shape of the skill profiles. The mean skill level of the operator in Plant J2a is some 40% higher than in Plant J1; and in Plant K2 it is nearly 80% higher then in Plant K1. In the centralized plants of both firms operators in the higher skill level categories now constitute all or most of the crews. There are however some notable differences between the two centralized plants. The Plant K2 profile which is skewed towards the highest skill levels retains some lower level manhours; the Plant J2a profile has no lower skill manhours, and the medium skill manhours still predominate over the highest skills.

The changes in the skill distributions between TL1 and TL2 were tested for statistical significance by two analyses of variance, one based on per unit output and the other on per plant basis. In each case variance estimates were obtained for three skill levels

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*Manhours by skill level have in each instance been related both to unit output (10^6 kwhr) and to plant operating hour. Tables and skill profile diagrams developed on these alternative bases are presented facing each other separately for Plants J1, J2a and for Plants K1, K2. The reasons for this expedient are explained on p. 48.

TABLE 5.2: DIRECT LABOR FORCE SKILL DISTRIBUTIONS FOR NON-CENTRALLY (TL1) AND CENTRALLY (TL2) CONTROLLED POWER PLANTS IN UTILITY J

(a) Basis: 10^6 kwhr

Organization: Electric Utility J

Process: Power Production by Steam-Electric Process

Technology (Level 1): Non-Centralized Control

Technology (Level 2): Centralized Control

Source of Data: Direct Observation and Firm's Records

Period: 1950-1952 (TL1) and 1964-1967 (TL2) [Data Acquired - Winter 1966]

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10^6kwhr			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
6										
High 5	449-530	0.0	3.3	+ 3.3	0.0	19.0	+19.0	0	1	+1
4	367-448	3.3	4.1	+ 0.8	10.0	23.6	+13.6	1	1	0
Medium 3	285-366	6.7	10.0	+ 3.3	20.0	57.4	+37.4	2	1	-1
2	203-284	16.7	0.0	-16.7	50.0	0.0	-50.0	3	0	-3
Low 1	121-202	6.7	0.0	- 6.7	20.0	0.0	-20.0	1	0	-1
0	38-120	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	33.4	17.4	-16.0	100.0	100.0	0.0	7	3	-4
	Net Manhour Change -47.9%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	267.0	59.8
Technology (Level 2)	367.4	57.9
Change	+100.4	

(b) Basis: Plant Operating Hour

Organization: Electric Utility J

Process: Power Production by Steam Electric Process

Technology (Level 1): Non-Centralized Control

Technology (Level 2): Centralized Control

Source of Data: Direct Observation and Firm's Records

Period: 1950-1952 (TL1) and 1964-1967 (TL2) [Data Acquired - Winter 1966]

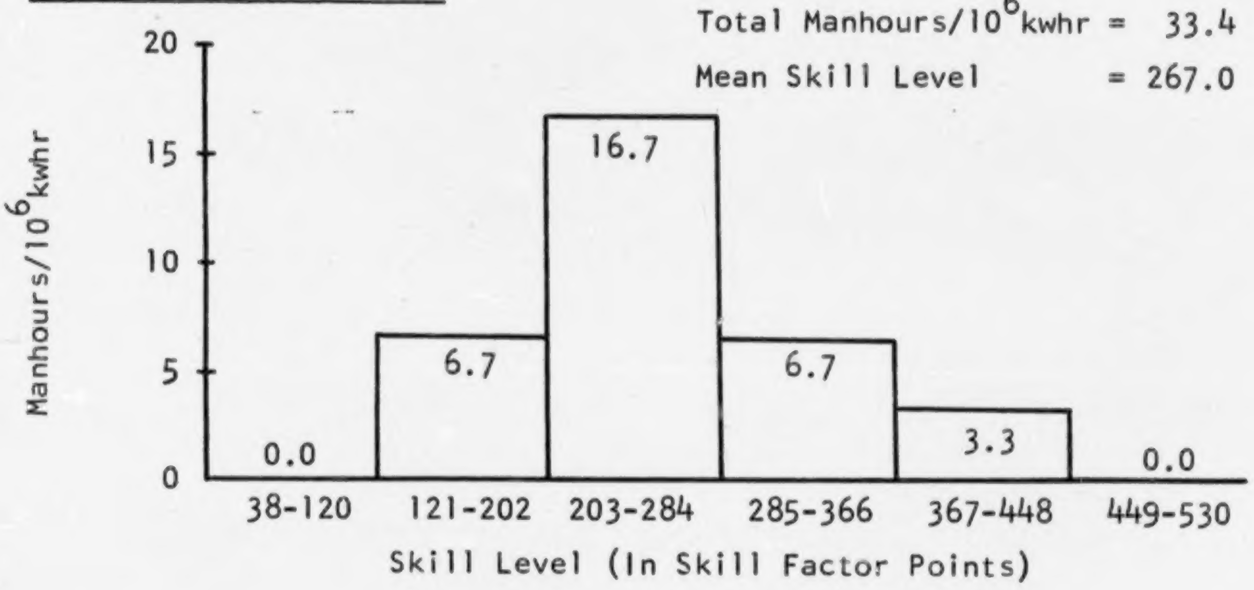
1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per Plant Operating Hour			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6										
5	449-530	0.0	1.0	+ 1.0	0.0	19.2	+19.2	0	1	+1
4	368-448	1.0	1.2	+ 0.2	10.0	23.1	+13.1	1	1	0
Medium 3	285-366	2.0	3.0	+ 1.0	20.0	57.7	+37.7	2	1	-1
2	203-284	5.0	0.0	- 5.0	50.0	0.0	-50.0	3	0	-3
Low 1	121-202	2.0	0.0	- 2.0	20.0	0.0	-20.0	1	0	-1
0	38-120	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	10.0	5.2	- 4.8	100.0	100.0	0.0	7	3	-4
	Manhour Change Due to Technological Change -48.0%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	267.0	59.8
Technology (Level 2)	367.4	57.9
Change	+100.4	

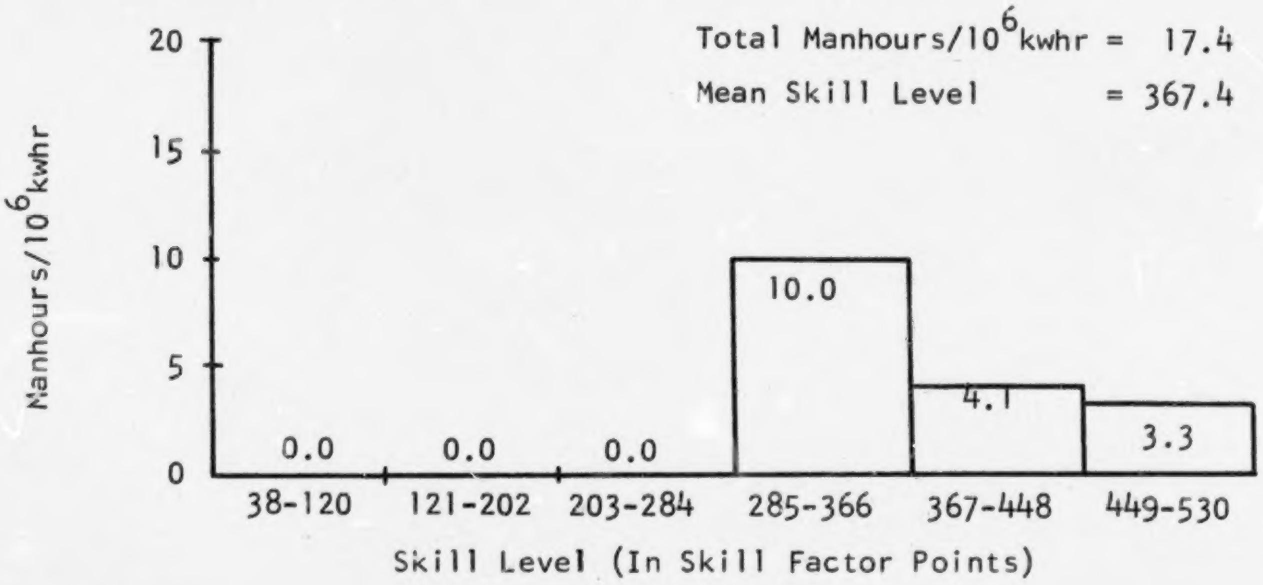
FIGURE 5.3: DIRECT LABOR FORCE SKILL PROFILES FOR NON-CENTRALLY (TL1) AND CENTRALLY (TL2) CONTROLLED POWER PLANTS IN UTILITY J

(a) Basis: 10^6 kwhr

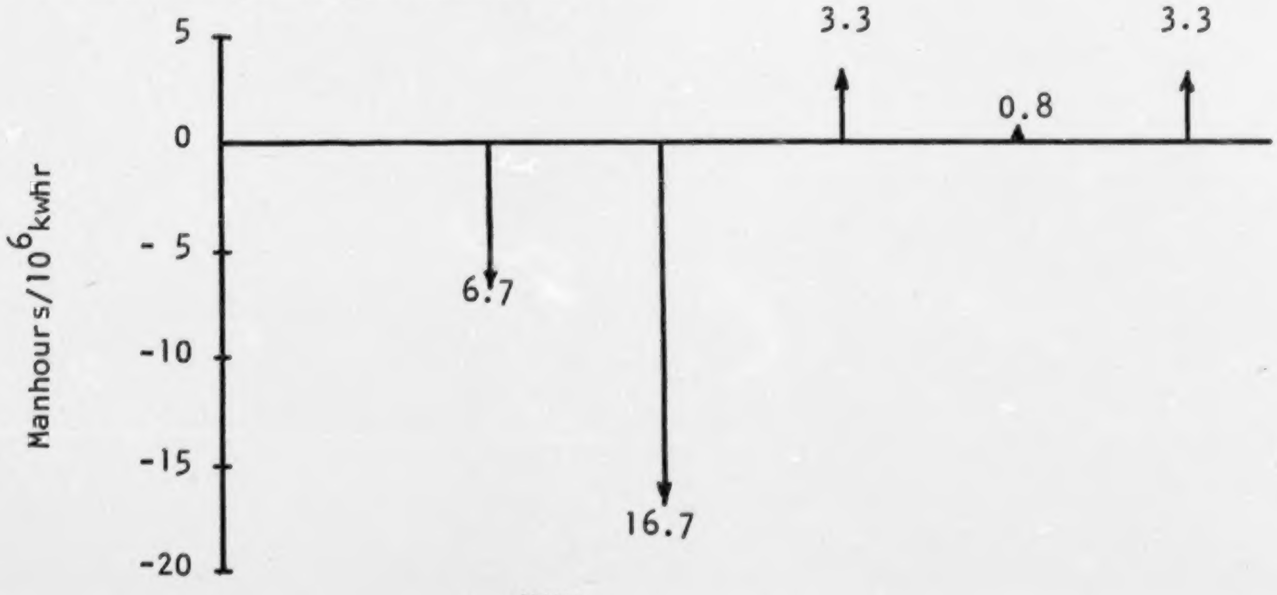
NON-CENTRALIZED CONTROL



CENTRALIZED CONTROL

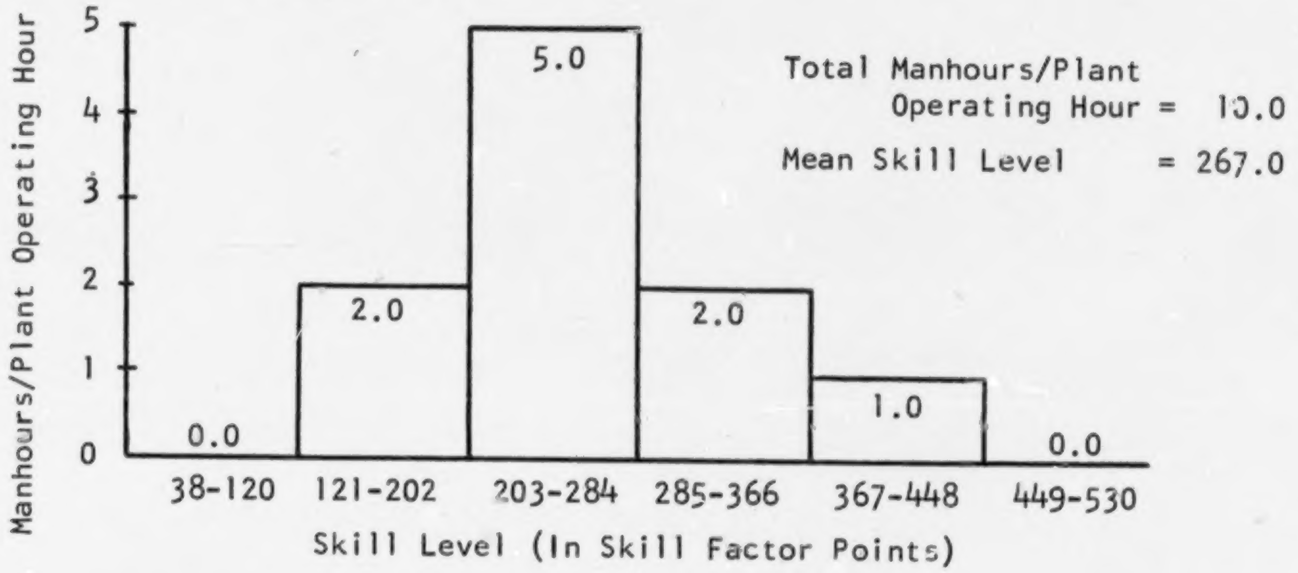


CHANGES - OLD TO NEW TECHNOLOGY

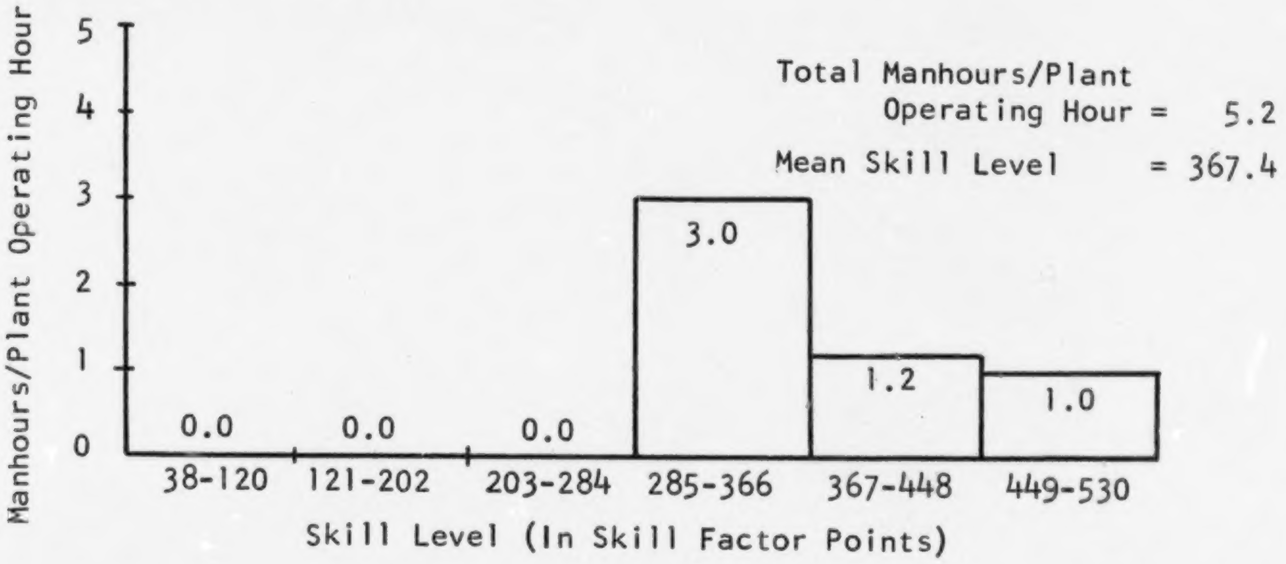


(b) Basis: Plant Operating Hour

NON-CENTRALIZED CONTROL



CENTRALIZED CONTROL



CHANGES - OLD TO NEW TECHNOLOGY

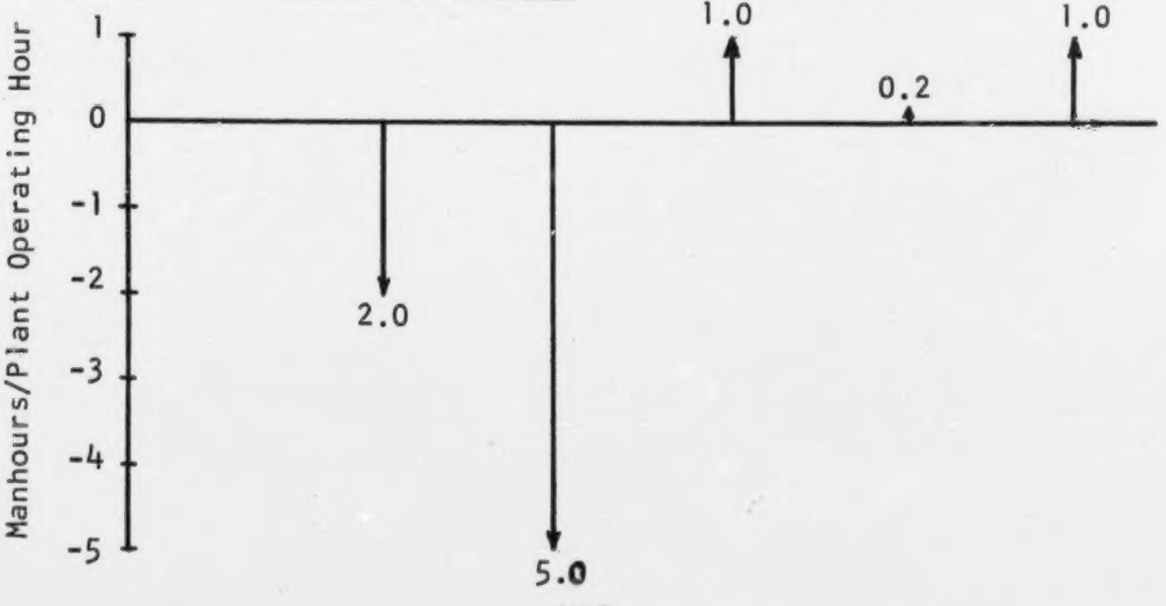


TABLE 5.3: DIRECT LABOR FORCE SKILL DISTRIBUTIONS FOR NON-CENTRALLY (TL1) AND CENTRALLY (TL2) CONTROLLED POWER PLANTS IN UTILITY K

(a) Basis: 10^6 kwhr

Organization: Electric Utility K

Process: Power Production by Steam-Electric Process

Technology (Level 1): Non-Centralized Control

Technology (Level 2): Centralized Control

Source of Data: Direct Observation and Firm's Records

Period: Winter 1967

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10^6 kwhr			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6										
5	449-530	0.0	3.0	+ 3.0	0.0	44.1	+44.1	0	2	+2
4	367-448	2.0	1.5	- 0.5	2.7	22.1	+19.4	1	1	0
Medium 3	285-366	8.2	1.5	- 6.7	10.8	22.1	+11.3	1	1	0
2	203-284	32.8	0.0	-32.8	43.3	0.0	-43.3	2	0	-2
Low 1	121-202	16.4	0.8	-15.6	21.6	11.7	- 9.9	1	1	0
0	38-120	16.4	0.0	-16.4	21.6	0.0	-21.6	1	0	-1
	Totals	75.8	6.8	-69.0	100.0	100.0	0.0	6	5	-1
	Net Manhour Change -91.0%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	216.4	77.4
Technology (Level 2)	386.7	91.3
Change	+170.3	

(b) Basis: Plant Operating Hour

Organization: Electric Utility K

Process: Power Production by Steam-Electric Process

Technology (Level 1): Non-Centralized Control

Technology (Level 2): Centralized Control

Source of Data: Direct Observation and Firm's Records

Period: Winter 1967

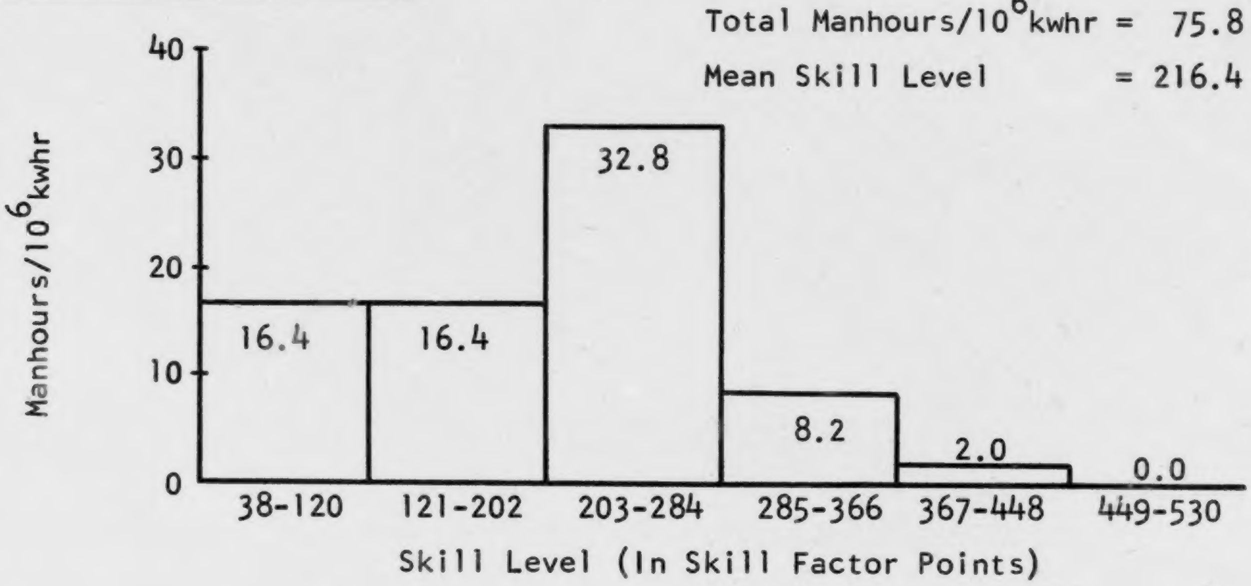
1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per Plant Operating Hour			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6										
5	449-530	0.0	2.0	+ 2.0	0.0	44.5	+44.5	0	2	+2
4	367-448	0.3	1.0	+ 0.7	3.2	22.2	+19.0	1	1	0
Medium 3	285-366	1.0	1.0	0.0	10.8	22.2	+11.4	1	1	0
2	203-284	4.0	0.0	- 4.0	43.0	0.0	-43.0	2	0	-2
Low 1	121-202	2.0	0.5	- 1.5	21.5	11.1	-10.4	1	1	0
0	38-120	2.0	0.0	- 2.0	21.5	0.0	-21.5	1	0	-1
	Totals	9.3	4.5	- 4.8	100.0	100.0	0.0	6	5	-1
	Manhour Change Due to Technology Change -51.6%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	216.4	77.4
Technology (Level 2)	386.7	91.3
Change	+170.3	

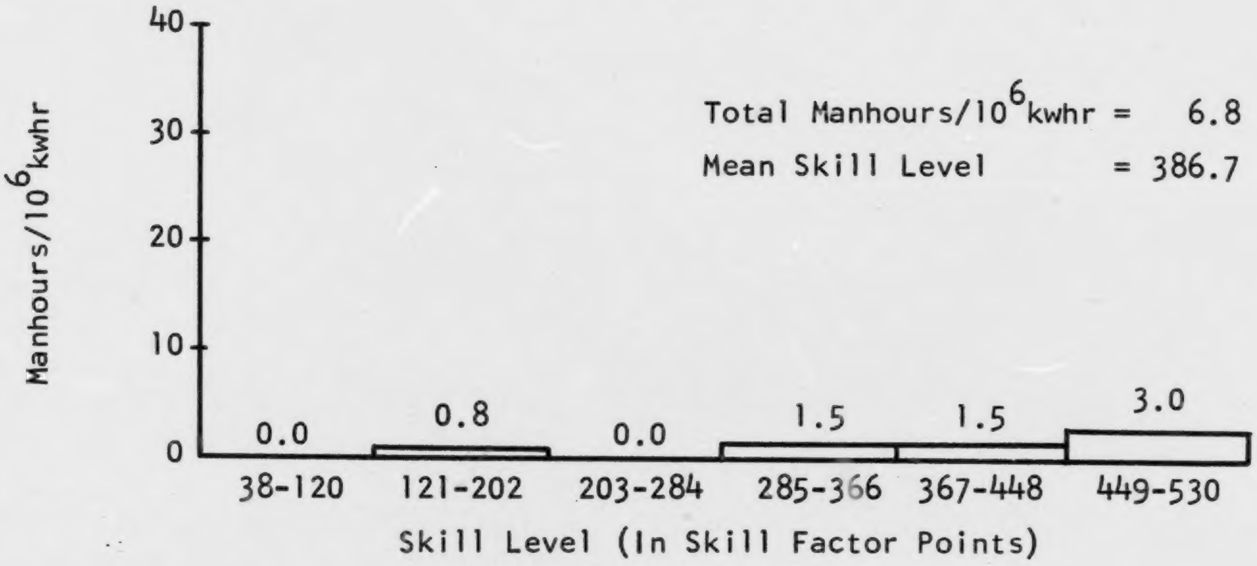
FIGURE 5.4: DIRECT LABOR FORCE SKILL PROFILES FOR NON-CENTRALLY (TL1) AND CENTRALLY (TL2) CONTROLLED POWER PLANTS IN UTILITY K

(a) Basis: 10^6 kwhr

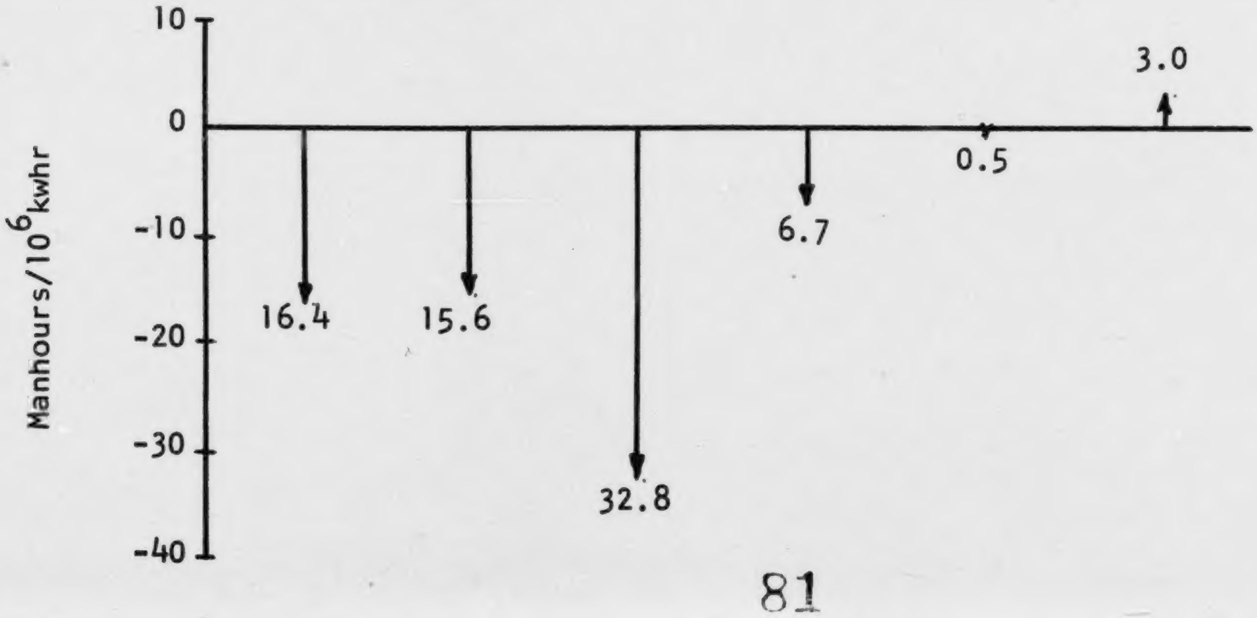
NON-CENTRALIZED CONTROL



CENTRALIZED CONTROL

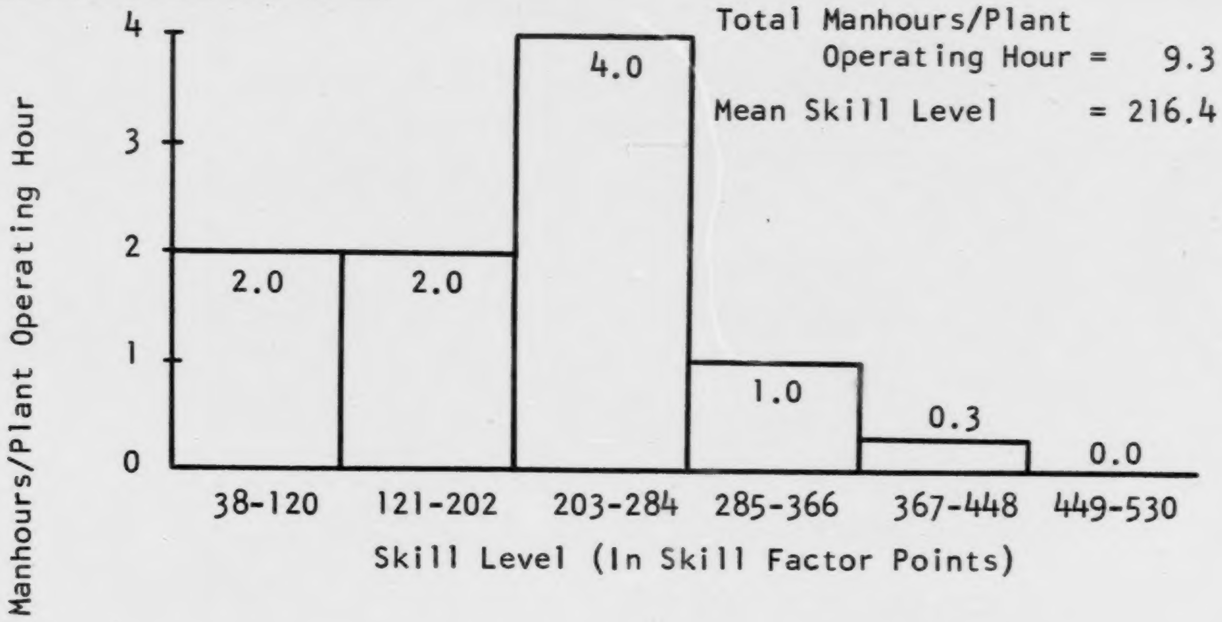


CHANGES - OLD TO NEW TECHNOLOGY



(b) Plant Operating Hour

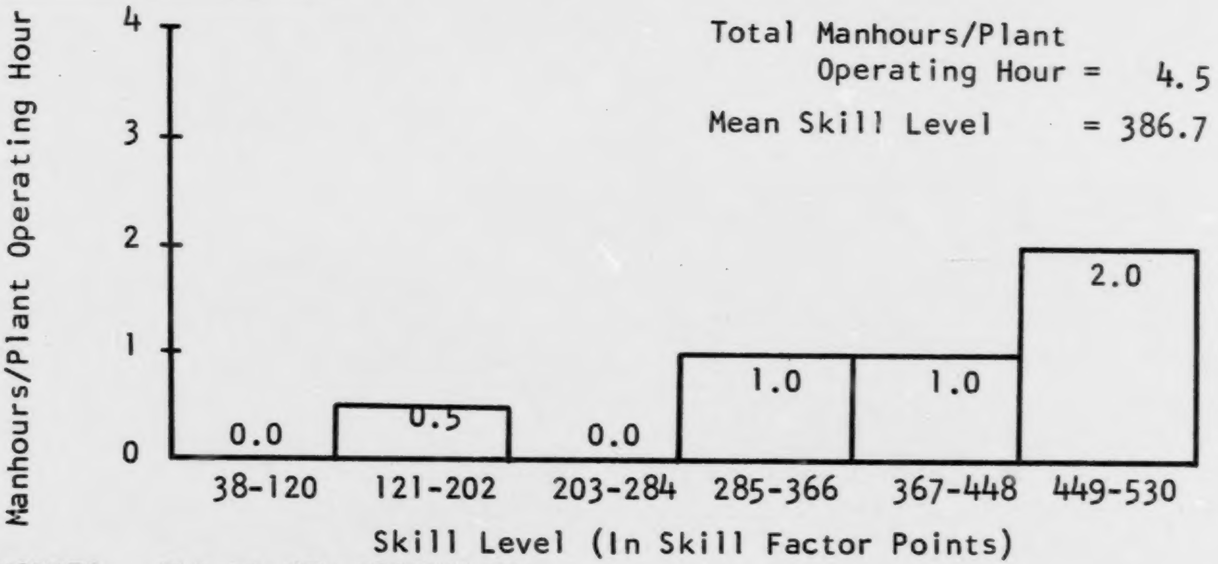
NON-CENTRALIZED CONTROL



Total Manhours/Plant Operating Hour = 9.3

Mean Skill Level = 216.4

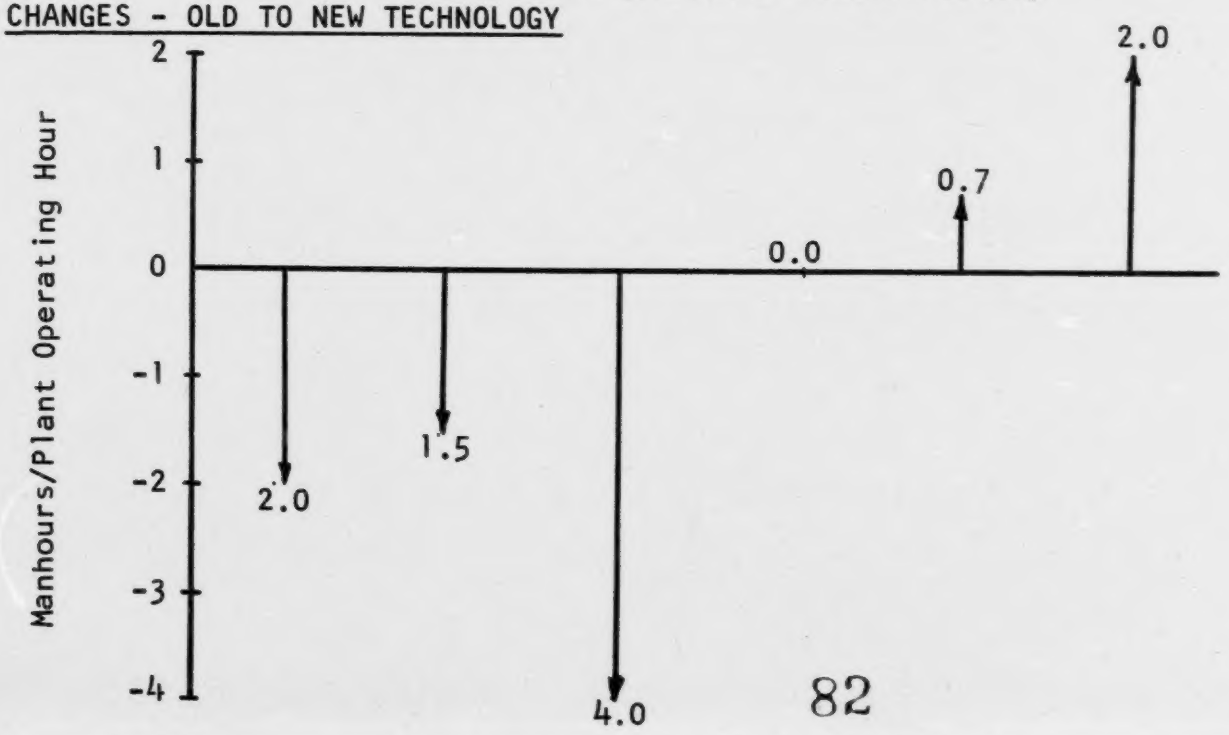
CENTRALIZED CONTROL



Total Manhours/Plant Operating Hour = 4.5

Mean Skill Level = 386.7

CHANGES - OLD TO NEW TECHNOLOGY



(lower, medium, higher) and for two technology levels (non-centralized, centralized), the "between firms" variance serving as a check on the bias introduced by differences between the firms. The figure of most interest is the variance ratio for the technology X skill level interaction which is in effect a measure of the extent to which the change in technology has affected skill requirements.

Owing mainly to the large difference in the output capacities of plants K1 and K2, reflected in a large residual or error variance, the analysis of the manhour per unit product data (Table 5.4a) yielded statistically non-significant results throughout. The same analysis based on manhours per plant operating hour (Table 5.4b) showed that the technology X skill level interaction contributes more than any other effect to the total variance. Expanded versions of Tables 5.4a and 5.4b will be found in Appendix C.

Changes in Skill Content

In both utilities the variety of job types decreased as a consequence of centralization: from 7 to 3 in Utility J, from 6 to 5 in Utility K. As foreshadowed in the profiles, new high skill level jobs were created and low skill level jobs eliminated.

Changes in Educational and On-the-Job Experience Requirements

Estimates of the educational levels of individual operators were made by the researchers after discussions with management personnel and are given in Appendix C. Benchmarks for the estimates of required on-the-job experience, which are also shown in this Appendix, were supplied by Utility J. The estimates were averaged over both firms, and the averaged values are given in Tables 5.5 and 5.6.

Judged by the respective mean educational levels, the operators in the centralized plants seem to require only slightly more of a general educational background then the operators in the older non-centralized plants. However, this slight rise reflects the complete elimination of operators without high school education. The centralized plants are staffed exclusively by high school graduates or near high school graduates.

Requirements for on-the-job experience have risen dramatically. The mean length of experience in the centralized plants is now 5 years, compared with less than $1\frac{1}{2}$ years in the non-centralized plants. It appears that any operator with less than two years experience is regarded as a trainee and is not allowed to take independent charge of the system. At the other end of the scale it is noteworthy that nearly one third of what are presumably key operators in the centralized plants are expected to have on-the-job experience exceeding $6\frac{1}{2}$ years; such a high requirement did not exist for any operators in the older system.

TABLE 5.4[*]: STATISTICAL SIGNIFICANCE TEST OF CHANGES IN SKILL LEVEL REQUIREMENTS ASSOCIATED WITH CHANGES IN TECHNOLOGY (DIRECT LABOR ONLY)

(a) Basis: 10^6 kwhrs

Source of Variance	D.F.	V.R.	Significance Level
Between Skill Levels	2	4.47	not significant
Between Technologies	1	12.37	
Between Firms	1	1.74	
SL x T	2	4.97	
SL x F	2	1.25	
T x F	1	4.85	

(b) Basis: Plant Operating Hour

Source of Variance	D.F.	V.R.	Significance Level
Between Skill Levels	2	19.92	$P < 0.025$
Between Technologies	1	19.94	$P < 0.025$
Between Firms	1	0.49	
SL x T	2	26.44	$P < 0.050$
SL x F	2	7.11	
T x F	1	0.00	

---

[*] Detailed data in Appendix C, Section 6.

TABLE 5.5: BEFORE AND AFTER CENTRALIZATION ESTIMATED HIGH SCHOOL EDUCATION REQUIREMENTS, POWER GENERATION, FIRMS J AND K (DIRECT LABOR ONLY)

High School Education (Years)	Average Manhours Per Plant Operating Hour			Average Manhours as % of Total for Each Technology Level		
	TL1	TL2	Change	TL1	TL2	Change
3 - 4	8.6	4.9	- 3.7	89.6	100.0	+10.4
1 - 2	0.0	0.0	0.0	0.0	0.0	0.0
0	1.0	0.0	- 1.0	10.4	0.0	- 10.4

Mean Educational Level	TL1	TL2
(Years of High School)	3.2	3.5

TABLE 5.6: BEFORE AND AFTER CENTRALIZATION ESTIMATED ON-THE-JOB EXPERIENCE REQUIREMENTS, POWER GENERATION, FIRMS J AND K

On-the-Job Experience (Months)	Average Manhours Per Plant Operating Hour			Average Manhours as % of Total for Each Technology Level		
	TL1	TL2	Change	TL1	TL2	Change
78 - 114	0.0	1.5	+ 1.5	0.0	30.6	+30.6
54 - 77	0.6	1.1	+ 0.5	6.2	22.5	+16.3
24 - 53	0.0	2.0	+ 2.0	0.0	40.8	+40.8
12 - 23	6.0	0.0	- 6.0	62.5	0.0	-62.5
0 - 11	3.0	0.3	- 2.7	31.3	6.1	-25.2

Mean Length of Experience	TL1	TL2
(Months)	16.8	60.1

It must thus be concluded that the high skill levels of the operators in a centralized plant are for the most part a result of the much extended on-the-job experience the operators have to undergo. Also the requirements for 3-4 years of high school education seems to be more strictly enforced: without this prerequisite operators are presumably not considered capable of absorbing the theoretical concepts and principles the mastery of which is coming to be regarded as a conditio sine qua non of reliable and effective control performance.

Composition and Structure of Indirect Labor in Power Plants of Utility J

Agreement was sought and obtained from Firm J to extend the data collection to cover the main components of its indirect labor force: maintenance and first line supervision. Not included in the study were clerical personnel and personnel classified as overhead--higher level supervision and plant engineers.

Unlike direct labor, which is permanently assigned to the plant equipment, maintenance and first line supervision divide their time between all the plants making up a generating station. Thus any changes in technology normally react on the structure and composition of indirect labor and this is especially so with the maintenance force. A good illustration is provided by the two plants K1 (non-centralized) and K2 (centralized). The changes that took place were as much actuated by the replacement of the header system by the unit system, as by the concentration of operating functions in a central control room. These two types of change tend to go together in power plants.

Replacement of header by unit systems was coincident with the realization that any gains accruing from the much more highly productive and reliable units would be more than cancelled out by prolonged layoffs,resulting from breakdowns occuring during the period between scheduled overhauls. One way of cutting down repair time would have been to build up the maintenance crews at each station--a very uneconomic solution as the crews would have been idle for long periods of time. Instead it was decided to reduce station maintenance by about a half and to set up a functionally independent Divisional Maintenance group under its own supervision. This group, made up of highly coordinated and specialized squads, carries out all overhaul work on a rotating schedule. At the request of Station Chiefs, squads are also dispatched at short notice to reinforce standing station maintenance crews in emergencies.

The second development was in response to the proliferation of instrumentation and control gear. Instrument maintenance personnel at each station was split off from general plant maintenance and subordinated to the Chief Plant Engineer.

A graphic representation of the change in organization that took place when J1 was converted to J2a is given in Figures 5.5 and 5.6, where the manpower covered by this report is shown in heavy outlines combined with cross hatching.

As was done in the case of the direct labor results, the manhours of the indirect labor components considered here will in each instance be presented on a per unit product basis (10^6 kwhr) and on a per plant operating hour basis. Changes in manhours per plant operating hour reflect exclusively the effects of technological changes, as they discount differences in plant capacity. Changes in manhours per unit product on the other hand show the net effect of both differences in capacity and/or changes in technology.

Indirect Labor Requirements in Plants J1 and J2a

Detailed breakdowns of maintenance manhours by skill level prorated to unit output (10^6 kwhr) and to plant operating hour are given in Tables C5a and C5b and Figures C13a and C13b in Appendix C, Section 9. The main results have been summarized in Table 5.7 below.

TABLE 5.7: CHANGES IN MAINTENANCE MANHOUR
AND SKILL REQUIREMENTS

Plant	Control System	Type	Capacity (MW)	Manhours Per 10^6 kwhr	Manhours Per Plant Operating Hour	Mean Skill Level	No. of Job Types
J1	Non-Centralized	Header	300	31.0	9.3	262.9	12
J2a	Centralized	Header	300	26.6	8.0	258.9	17

Since both plants have header systems and their capacity is also the same, it would be easy to conclude that the 14% reduction in manhour requirements must have been a direct result of centralization. In fact, however, centralization coincided with the creation of the Divisional Maintenance group and the simultaneous curtailment of station (in-plant) maintenance crews; and the policy decision back of this organizational change seems to have been mainly based on the replacement of header generating systems by unit systems in other plants of the Utility Company J. It is doubtful, to say the least, that centralization had any appreciable influence on the decision.

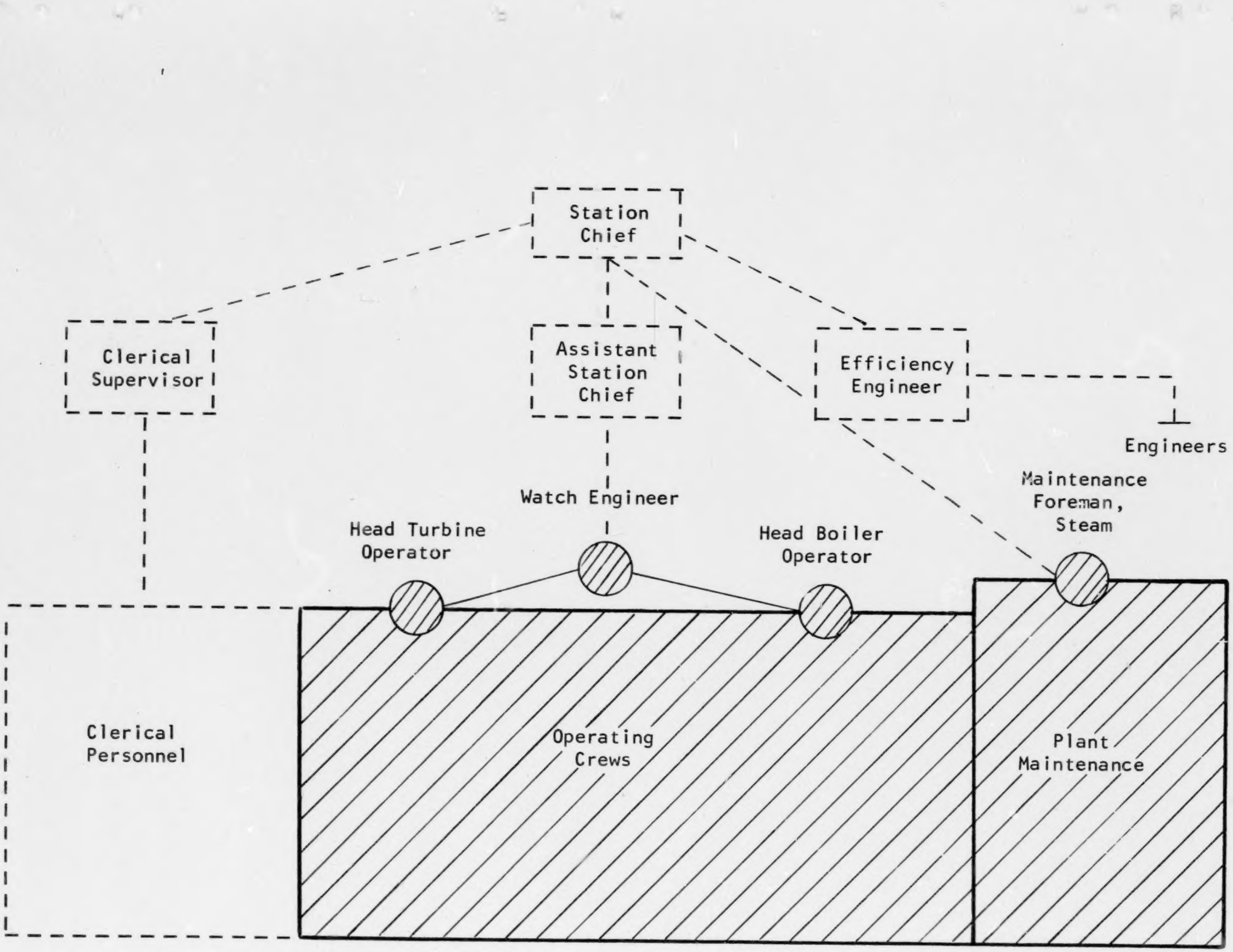

Station Chief
Clerical Supervisor
Assistant Station Chief
Efficiency Engineer
Engineers
Watch Engineer
Maintenance Foreman, Steam
Head Turbine Operator
Head Boiler Operator
Clerical Personnel
Operating Crews
Plant Maintenance

FIGURE 5.5: UTILITY J STATION ORGANIZATION CHART AT TECHNOLOGY LEVEL 1

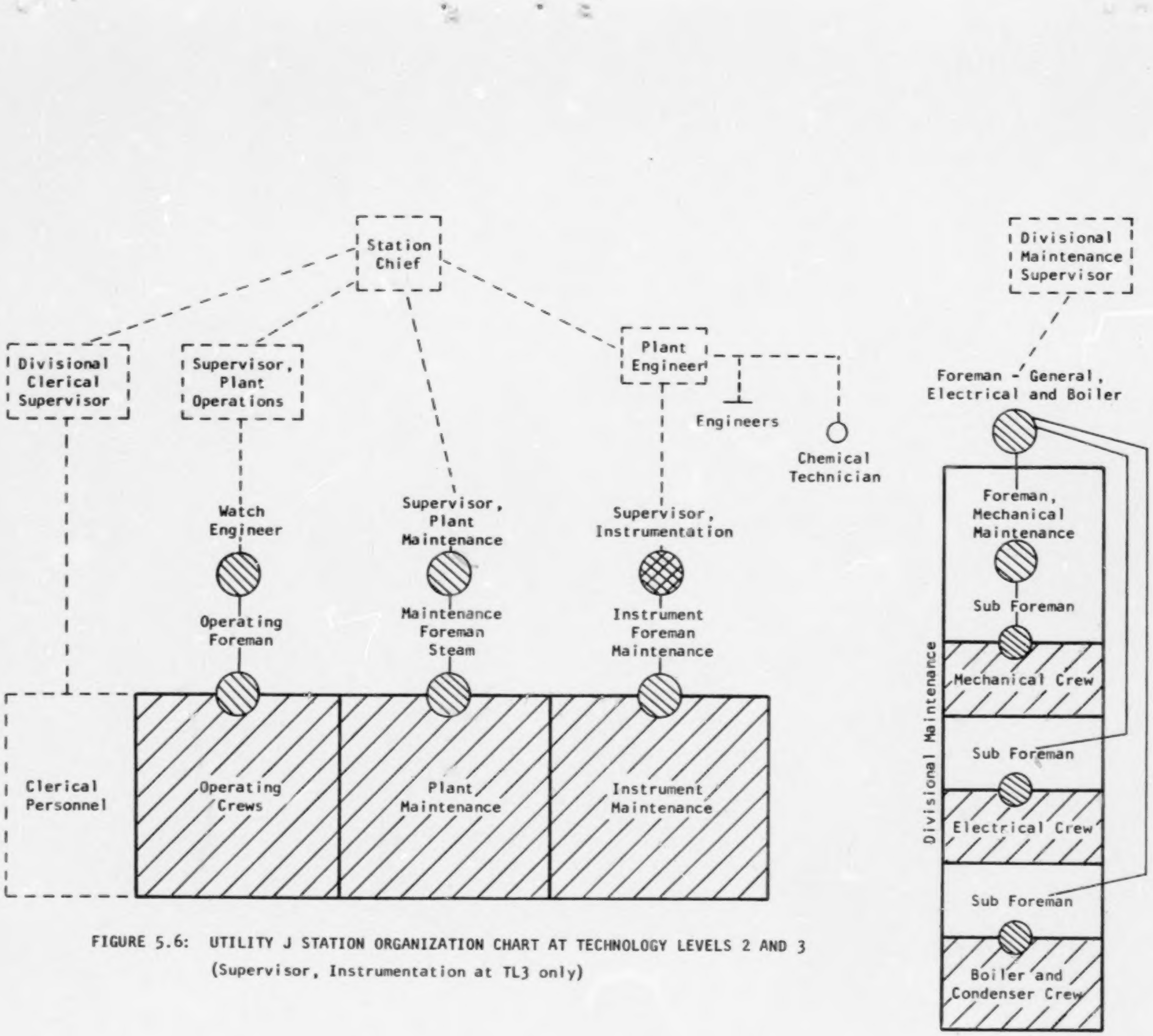

Station Chief
Divisional Clerical Supervisor
Supervisor, Plant Operations
Plant Engineer
Engineers
Chemical Technician
Watch Engineer
Supervisor, Plant Maintenance
Supervisor, Instrumentation
Operating Foreman
Maintenance Foreman Steam
Instrument Foreman Maintenance
Clerical Personnel
Operating Crews
Plant Maintenance
Instrument Maintenance
Divisional Maintenance Supervisor
Foreman - General, Electrical and Boiler
Foreman, Mechanical Maintenance
Sub Foreman
Mechanical Crew
Sub Foreman
Electrical Crew
Sub Foreman
Boiler and Condenser Crew
Divisional Maintenance

FIGURE 5.6: UTILITY J STATION ORGANIZATION CHART AT TECHNOLOGY LEVELS 2 AND 3
(Supervisor, Instrumentation at TL3 only)

The decrease in mean skill level is no more than a chance effect. More noteworthy is the rise in the number of job types from 12 to 17. another immediate consequence of the setting up of Divisional Maintenance. It confirms, if confirmation is needed, the intended increase in specialization of the maintenance force.

A summary of the differences in supervisory manhours and skill requirements in Plants J1 and J2a is given in Table 5.8, the total differences being mainly determined by the reduced requirement for operating supervision.

TABLE 5.8: CHANGES IN FIRST-LINE SUPERVISION (OPERATING AND MAINTENANCE) MANHOUR AND SKILL REQUIREMENTS

Plant	Supervision	Manhours Per 10^6 kwhr	Manhours Per Plant Optg. Hr.	No. of Job Types	Mean Skill Level
J1	Operating	10.40	3.12	4	455.6
	Maintenance	0.80	0.24	1	462.0
	Total	11.20	3.36	5	Average 456.1
J2a	Operating	3.73	1.12	3	485.9
	Maintenance	1.77	0.53	8	469.5
	Total	5.50	1.65	11	Average 480.7

Total supervisory manhours in Plant J2a are almost exactly half of those in Plant J1, the operating supervision manhours alone having decreased by nearly two thirds. This decrease was directly connected with centralization of control, when a single Operating Foreman replaced a Head Boiler Operator and a Head Turbine Operator, both supervisory positions (see Figure 5.6). The countervailing increase in maintenance supervision manhours mainly reflects the setting up of Divisional Maintenance; as evident from the next to last column of Table 5.8, seven new supervisory positions were created for the new groups.

The mean skill level of the entire first-line supervision (based on the researchers' estimates), which has risen by about 6% on average, suggests that supervisors of a higher caliber are required in the centralized plant; this applies especially to the operating supervisors.

Changes in Aggregate Labor Inputs by Skill Level

To provide a comprehensive view of the manpower and skill effects of centralization of power plant control, the results of the direct and indirect labor studies in the plants of Utility J have been pooled and are presented in Figures 5.7a and 5.7b.

As the non-centralized and centralized Plants J1 and J2a have the same generating capacities, and any manhour and skill changes observed could thus only be due to changes in technology, it was immaterial whether the per unit output or the per plant operating hour basis was used. The per unit output basis is in fact used in Table 5.9 to show the absolute and relative manhour inputs of each component of the work force.

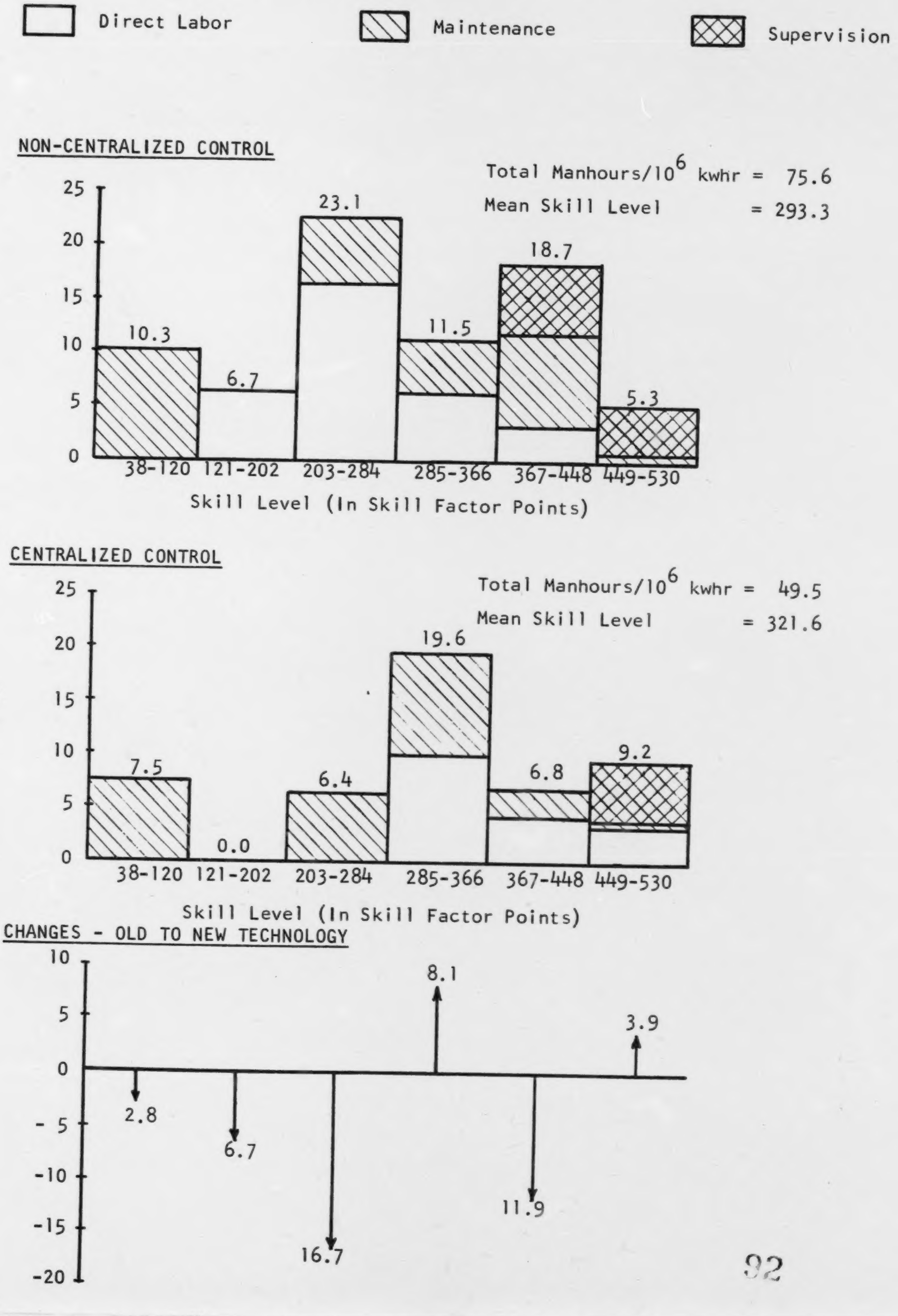
TABLE 5.9: AGGREGATE CHANGES IN DIRECT AND INDIRECT LABOR MANHOUR REQUIREMENTS

	Manhours Per 10^6 kwhr			Manhours as % of Total for Each Technology Level	
	TL1	TL2	% Change	TL1	TL2
Direct Labor	33.4	17.4	-48	44	35
Indirect Labor	42.2	32.1	-24	56	65
Maintenance	31.0	26.6	-14	41	54
Supervisory	11.2	5.5	-51	15	11
Clerical	small	small	-	-	-
Totals	75.6	49.5	-35	100	100

The overall effect of centralization has been a one third reduction in total manhour requirements, the direct labor inputs having been cut by nearly one half, the indirect labor inputs by nearly a fourth. As a result the preponderance of indirect over direct labor has increased to the point where the latter component supplies two thirds of the total manhour input, the raised maintenance requirements being the main contributing factor. Supervision which accounted for 15% of the total input at TL1 accounts for only just over 10% in the centralized plant.

FIGURE 5.7: COMPOSITE SKILL PROFILES FOR TOTAL LABOR FORCE IN POWER PLANTS J1 (NON-CENTRALIZED CONTROL) AND J2a (CENTRALIZED CONTROL)

(a) Basis: 10^6 kwhr

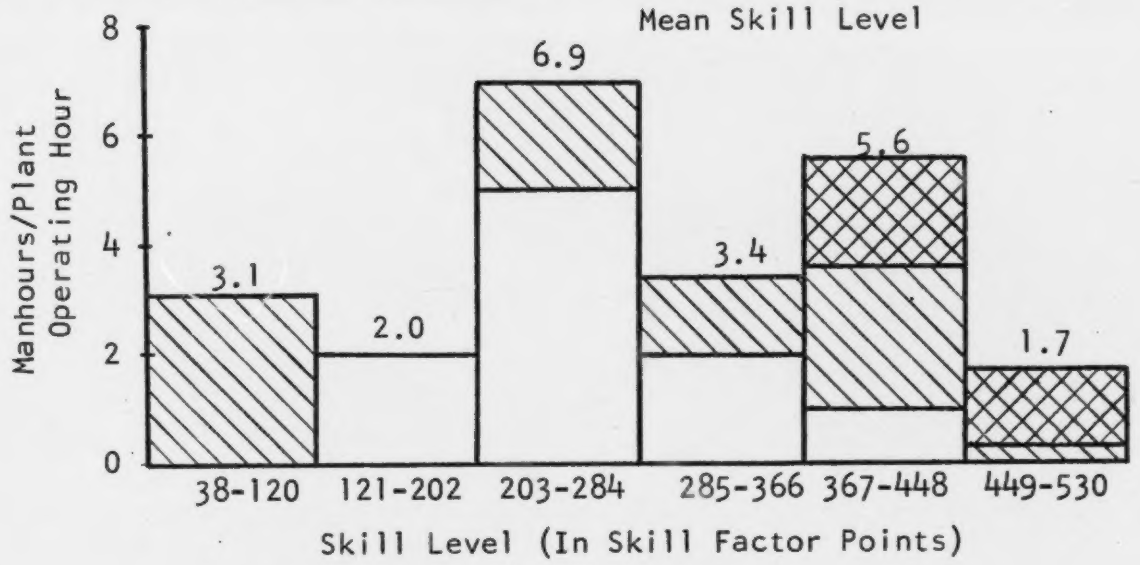


(b) Basis: Plant Operating Hour

☐ Direct Labor ▧ Maintenance ▩ Supervision

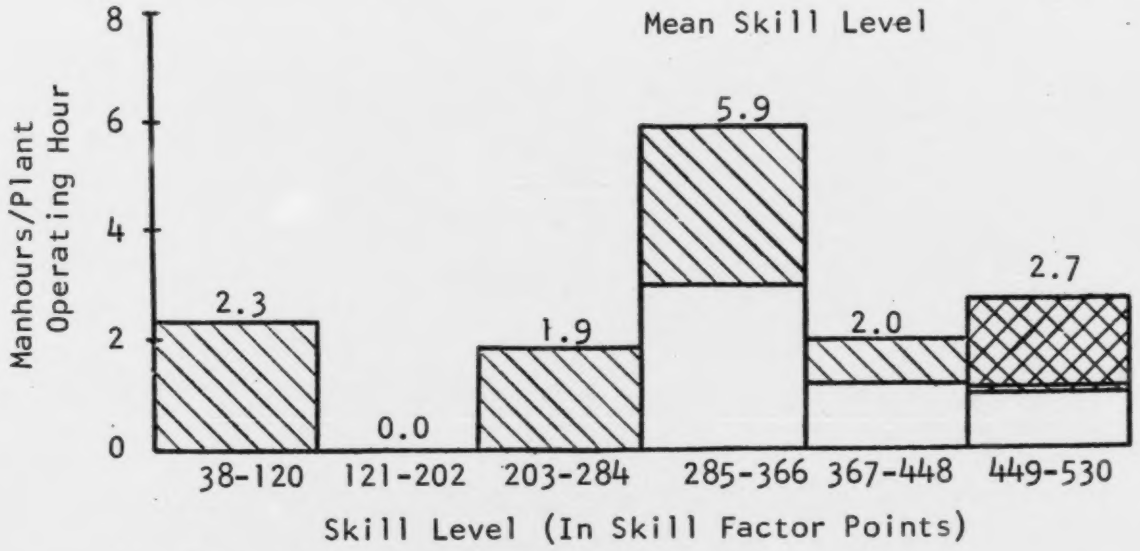
NON-CENTRALIZED CONTROL

Total Manhours/Plant Operating Hour = 22.7
Mean Skill Level = 293.8



CENTRALIZED CONTROL

Total Manhours/Plant Operating Hour = 14.8
Mean Skill Level = 321.6



CHANGES - OLD TO NEW TECHNOLOGY

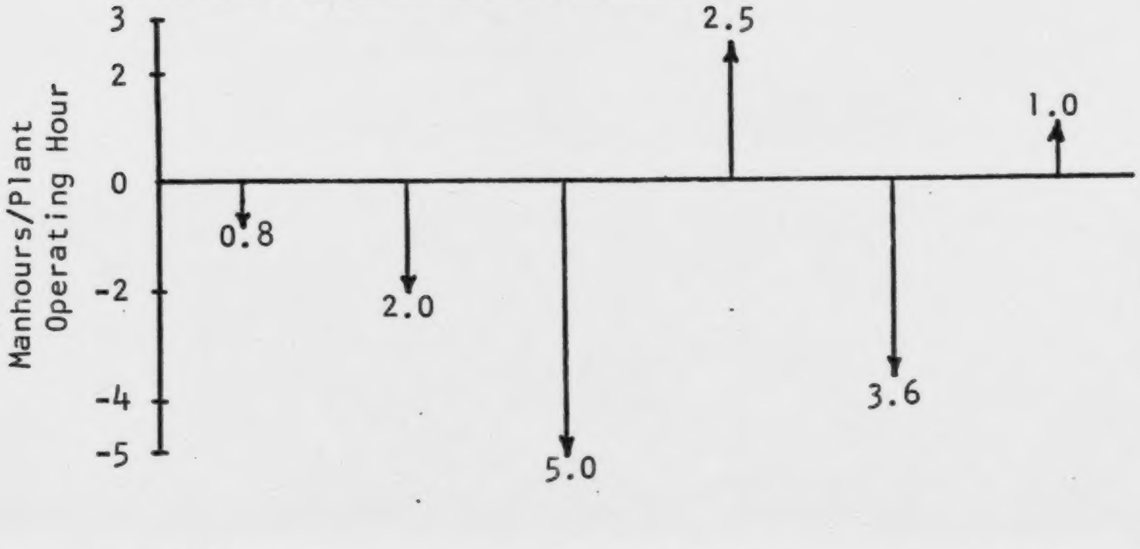


Table 5.10 shows the mean skill levels at both technology levels. Contrary to expectations, the newer technology appears to require greatly increased skills from direct labor, while maintenance skills have remained about the same as at TL1, and are at TL2 substantially below those of the direct labor force. Supervisory skill requirements too have risen.

TABLE 5.10: AGGREGATE CHANGES IN DIRECT AND INDIRECT LABOR SKILL REQUIREMENTS

	TL1	TL2	% Change
Direct Labor	267.0	367.4	+43.8
Maintenance	262.9	258.9	- 1.8
Supervisory	456.1	480.7	+ 5.9
All Labor	293.3	321.6	+11.1

Comparison of the shapes of the skill profiles for the aggregate labor inputs (Figures 5.7a and 5.7b) indicates a pronounced shift toward the higher end of the skill scale. Whereas at TL1 over 80% of all manhours were at low and lower medium skill levels, their share has shrunk to little over 25% after centralization.

5.4 Discussion of Effects of Centralization of Control

Concentration of control activities in central control rooms is not usually regarded as a distinct aspect of automation, either because the control activities themselves are little affected, or because centralization is overshadowed by the coincident installation of process computers, in which case any subsequent effects in production or productivity tend to be ascribed to the computer. What is overlooked is that centralization always poses some very intricate problems of automatic control design which, once solved, advance the system most of the way towards computerization, regardless of whether or not a computer is actually installed. The studies of steam electric power plants reported in Chapter 5, and in Section 6.2 of Chapter 6, helped to highlight this fact through the comparisons they permitted between non-centralized and centralized plants on the one hand, and centralized and centralized/computerized plants on the other.

The impact of centralization on the manpower requirements in steam electric power plants was found to be considerable, and there is every reason to assume that centralization has had, or will have, similar effects wherever it takes place. As would be expected, the change affects the operating crews (direct labor manhours) most markedly, reducing them by 50% in the case studied. The crews in the central control rooms consisted throughout of operators with prolonged experience and greater skill, the requirement for low skills and most medium skills being small.

Per unit indirect labor manhour requirements were also reduced, but to a lesser degree. As a result, maintenance manhours overtook direct labor manhour inputs, a development which parallels that observed in the steel strip annealing process. This preponderance of maintenance labor suggests that this production system is entering what we have termed the "labor-static" phase of technology, where the size of the labor force becomes partly or wholly inelastic with respect to demand and volume of production.

The skill profiles for the total manpower input show that medium skill levels preponderate, accounting for approximately half of the entire input. A further third of the input is at higher skill levels. Skillwise, the composition of the workforce is likely to remain stable, though output per manhour is likely to increase further, due to increases in capacity of the newer plants.

CHAPTER 6: IMPACT OF THE APPLICATION OF DIGITAL PROCESS-CONTROL COMPUTERS ONSKILL DEMANDS OF CONTINUOUS-FLOW PROCESSES (DIRECT AND INDIRECT LABOR)

6.1 Standard Automatic Control vs. Computer Control of Continuous Manufacturing Processes

The introduction of digital computers for online real-time monitoring and control of manufacturing processes represents a distinct stage of automation, which in principle can have a major effect on manpower, since for the first time it permits fully automatic (unattended) operation. It is a new development, since the first known applications date only from the late 1950's, and in 1963 there were only some 200 process-control computers in the U.S.A. The current growth rate indicates that there will be about 1,500 by 1970, aggregated over all industries.

At the time of submitting the proposal (December 1965) our technological familiarity with this type of development was strictly limited, and our initial research efforts were therefore directed towards acquiring more detailed information on processes and applications of computers in various industries. Visits were made to oil refineries, cement plants, air products plants and electric power plants.

It became clear both from the literature survey and from these visits that there are several technologically distinct types of online computer application, with markedly different allocations of operating functions as between computer equipment, conventional automatic-control equipment and men (including operating crew, maintenance force and management). The matrix on page 77 sets out the technological options actually encountered in out studies.

"A" indicates the normal allocation of function in a fully "manually controlled" plant, such as an older cement kiln; "B" describes a normal modern automatically-controlled plant such as a newer cement kiln or oil refinery process without a computer; C_1 and C_2 show two types of what may be called "computer-aided" automatic-control situations in which the plant is regulated by a number of independently operating analog (usually pneumatic) automatic controllers with manually adjusted set-points. The computer in this case serves two functions: 1) to log data and make performance calculations which serve as a basis for set-point changes which are actually carried out by technical staff or operating crews; and/or 2) to scan instruments, detect the occurrence of nonstandard conditions requiring remedial action and draw the operating crew's attention to them, without actually initiating corrective actions. This is known as "open-loop" on-line computer application. In certain cases the computer may also control start-up and shutdown sequences.

The currently most advanced on-line computer-controlled process plants (e.g., air separation plant) have functions allotted as in D. In this case the operating crew has been displaced entirely by a combination of analog automatic controllers and a computer, and any functions that cannot be carried out by the computer are allocated to technical staff on an intermittent basis. A further technological development known as direct-digital control (DDC), at present rarely applied, transfers routine control functions from numerous conventional analog devices to the (single) computer, operating on a time-shared basis. When it does appear in quantity, DDC appears likely to have little or no further manpower impact, representing simply a transfer of control from one hardware device to another.

While, given the great number of possible distributions of function between operating crew and analog and digital automatic-control devices, the four technological stages described above are by no means mutually exclusive or clearly demarcated, they do seem sufficiently well defined to permit comparative manpower and skill studies of the type desired.

The overall pattern of case study finally selected is set out in the following table:

PROCESS	TECHNOLOGICAL LEVEL		
	1	2	3
Steam Electric Generation Plants	Conventional Automatic Control	Computer Control (Type C_1 and C_2)	
Catalytic Crackers (Oil Industry)	Conventional Automatic Control	Computer Control (Type C_1 and C_2)	
Air Separation	Semi-Automatic Control		Fully Computer Controlled (Unattended)

Though showing a number of interesting features, computer control in the cement industry was rejected as unsuitable for further study for several reasons, the major one being that the computer-control system was evidently not fully operational in the plant visited. The picture in the plants visited was also complicated by a number of overlapping technological and organizational advances whose effects would have been difficult to isolate, among them better thermal

PROCESS CONTROL COMPUTERS: FEASIBLE PATTERN OF ALLOCATION OF FUNCTION AS BETWEEN OPERATING CREW, CONVENTIONAL ANALOG CONTROL DEVICES AND COMPUTER

Performer	\ Function	Start-up, shutdown	Maintaining desired running conditions	Supervisory control and optimization		Fault conditions	
				Status evaluation	Action	Detection	Diagnoses and action
Manpower	Operating crew	A, B, C	A		A, B, C	A, B, C	C
	Management and technical staff	D		A, B			A, B, D
Machine	Conventional (analog) automatic control devices		B, C				
	Computer	C*, D*	D	C, D	D	C*, D	

*in advanced cases

System Configuration

A = Manual control

B = Conventional (analog) automatic control

C = Level 1 computer control ("open-loop")

D = Level 2 computer control ("closed-loop") design of kilns, centralization of operating facilities, increased scale of plant, different and better materials-handling facilities, and improved sampling and laboratory testing methods.

The remainder of this chapter sets out the results of the three studies listed in the table above, each being treated as a self-contained whole.

6.2 Process Computers in Electricity Generation

Process Description*

Digital process computers started to be included in power plant design in the early 1960's, less than a decade after centralized plants had come into operation. Very likely these two developments were not unconnected, at least in the minds of some managements, though there also appeared to be a widespread appreciation on the part of engineers of the difficulties connected with computerization. In the upshot, the amount of control transferred to the first computers installed was and remains small. In one of the two utilities, the feeling that computers were not paying their way became so pronounced and prevalent that they were left out of the design of the firm's newest plant altogether. Evidently the realization of the computer's full potential is contingent on further advances in automatic control and in computer reliability and enhanced process control capability.

These considerations have a direct bearing on the studies and results reported here. Managements of neither of the two "computerized" Plants J3 and K3 look upon these installations as being in any significant sense under computer control, with the possible exception of start-up and shutdown operations; but as already mentioned, these are rare events. Computers are thus perceived mainly as means of keeping operators currently appraised of the state of the system and of alerting them to developments calling for urgent attention or intervention.

A summary of the main characteristics of the four plants representative of centralized (TL2) and centralized/computerized (TL3) control is given in Table 6.1.

The two computerized Plants J3 and K3 are remarkably similar in most characteristics, especially in their total generating capacity and the number of operating equipment units. This also holds for Plant K2 which, except for the computer, is identical with Plant K3 in every major respect. But even Plants J2b and J3 are not unlike, at least in the number of "units" of which they are made up. Because of the desire to keep this variable controlled,

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*For a general description of power generation processes and control technology, see Chapter 5 and Appendix C. For specifics of the computer applications see Appendix C.

Plant J2b was preferred to the 7 boiler, 4 turbine/generator Plant J2a used in the preceding chapter. That J2b has a lower generating capacity than the three other plants used in this study is from our point of view an advantage: it enables a separation of manpower effects due to changes in control technology from those due to sheer increase in capacity.

Detailed flow diagrams of Plants J2b, J3 and K3 which also include manning charts and control point locations are given in Figures C-8, C-9 and C-12 in Appendix C.

Installation of process computers has not affected the organizational structure which had become established with centralization. Nor were the existing training procedures affected in any substantial respect: according to the managements in both firms hardly more was involved than familiarizing operators with the meaning of alarm messages and of methods of entering the computer memory store to determine system status. The problem of interpreting the print-outs which appear in coded form, has been partly overcome by providing a dictionary; but this is only an interim solution to be ultimately superseded by printing the messages in English.

Changes in Manhour Requirements by Skill Level* (Direct Labor Only)

All that has been said up to this point adds up to the expectation of little or no changes in manning, or in the skill level of the labor force. This expectation is borne out by the analysis of the labor inputs, whether total or broken down by skill levels.

The absence of any change is incisively demonstrated in the skill profiles contrasting Plants K2 and K3. As the two plants are identical in total generating capacity, the change in manhour inputs, whether considered on the unit product (Table 6.3a and Figure 6.2a) or on the per plant (Table 6.3b and Figure 6.2b) basis, would be exclusively referrable to the change in control--to the introduction of the computer. There is no evidence of any change, either in the total labor input nor in the inputs at the various skill levels.

In the second utility company, the results of the comparisons between centralized Plant J2b and centralized/computerized Plant J3 are different, depending on the basis adopted. Table 6.2b and Figure 6.1b, which show the data and profiles on the per plant basis, indicate no difference between the number of manhours used and no difference in the shapes of the profiles. In other words, the

---

*Manhours by skill level have in each instance been related both to unit output (10^6 kwhr) and to plant operating hour. Tables and skill profile diagrams developed on these alternative but complementary bases are presented facing each other, separately for Plants J2b, J3 and for Plants K2 and K3. The reasons for this expedient are explained on page 48.

TABLE 6.1: CHARACTERISTICS OF NON-COMPUTERIZED (TL2) AND COMPUTERIZED (TL3) POWER PLANTS

Plant Code Name	J2b	J3	K2	K3
Built in	1957	1963	1961	1964
Control Technology (Technology Level)	Centralized (TL2)	Centralized/ Computerized (TL3)	Centralized (TL2)	Centralized/ Computerized (TL3)
Main Plant Design Features	Unit System with Tandem Compound, Triple Flow Turbine Units	Unit System with Cross-Compound, Single Flow Turbine Units	Unit System with Cross-Compound, Four Flow Turbine Units	As K2
Generating Capacity	350 MW	640 MW	660 MW	660 MW
Number of Boilers	2	2	2	2
Number of Turbine-Generators	2	2	2	2
Steam Generating Capacity Per Boiler	1,140,000 lb/hr	2,305,000 lb/hr	2,160,000 lb/hr	2,160,000 lb/hr
Capacity of Each Turbine-Generator	175 MW	320 MW	330 MW	330 MW

TABLE 6.2: DIRECT LABOR SKILL DISTRIBUTIONS FOR NON-COMPUTERIZES (TL2) AND COMPUTERIZED (TL3) POWER PLANTS IN UTILITY J

(a) Basis: 10^6kwhr

Organization: Electric Utility J

Process: Power Production by Steam-Electric Process

Technology (Level 2): Centralized Control

Technology (Level 3): Centralized/Computerized Control

Source of Data: Direct Observation and Firm's Records

Period: 1962-1966 (TL2) and 1964-1967 (TL3) [Data Acquired - Winter 1967]

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10^6kwhr			Manhours as % of Total for Technology Level			Number of Job Types		
		TL2	TL3	Change	TL2	TL3	Change	TL2	TL3	Change
High 6										
5	449-530	2.9	1.6	- 1.3	25.2	25.4	+ 0.2	1	1	0
4	367-448	2.9	1.6	- 1.3	25.2	25.4	+ 0.2	1	1	0
Medium 3	285-366	5.7	3.1	- 2.6	49.6	49.2	- 0.4	1	1	0
2	203-284	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Low 1	121-202	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0	38-120	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	11.5	6.3	- 5.2	100.0	100.0	0.0	3	3	0
	Net Manhour Change -45.2%									

	Mean Skill Level	Standard Deviation
Technology (Level 2)	377.0	60.3
Technology (Level 3)	377.0	60.3
Change	0.0	

(b) Basis: Plant Operating Hour

Organization: Electric Utility J

Process: Power Production by Steam-Electric Process

Technology (Level 2): Centralized Control

Technology (Level 3): Centralized/Computerized Control

Source of Data: Direct Observation and Firm's Records

Period: 1962-1966 (T12) and 1964-1967 (TL3) [Data Acquired - Winter 1967]

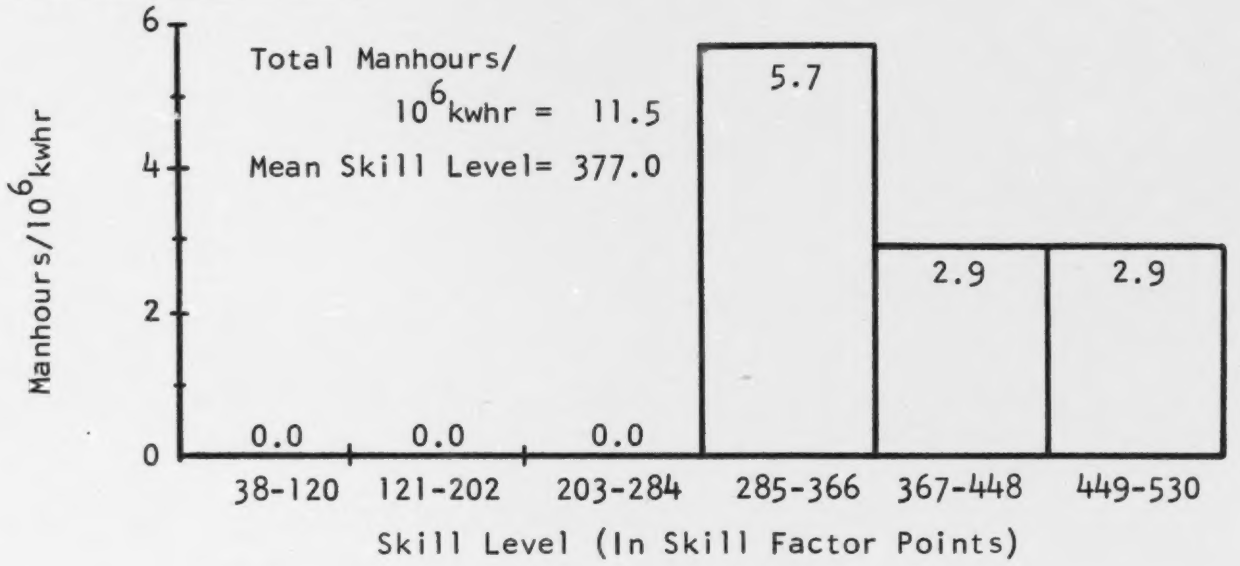
1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per Plant Operating Hour			Manhours as % of Total for Technology Level			Number of Job Types		
		TL2	TL3	Change	TL2	TL3	Change	TL2	TL3	Change
High 6										
5	449-530	1.0	1.0	0.0	25.0	25.0	0.0	1	1	0
4	367-448	1.0	1.0	0.0	25.0	25.0	0.0	1	1	0
Medium 3	285-366	2.0	2.0	0.0	50.0	50.0	0.0	1	1	0
2	203-284	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Low 1	121-202	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0	38-120	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	4.0	4.0	0.0	100.0	100.0	0.0	3	3	0
	Manhour Change Due to Technology Change 0.0%									

	Mean Skill Level	Standard Deviation
Technology (Level 2)	377.0	60.3
Technology (Level 3)	377.0	60.3
Change	0.0	

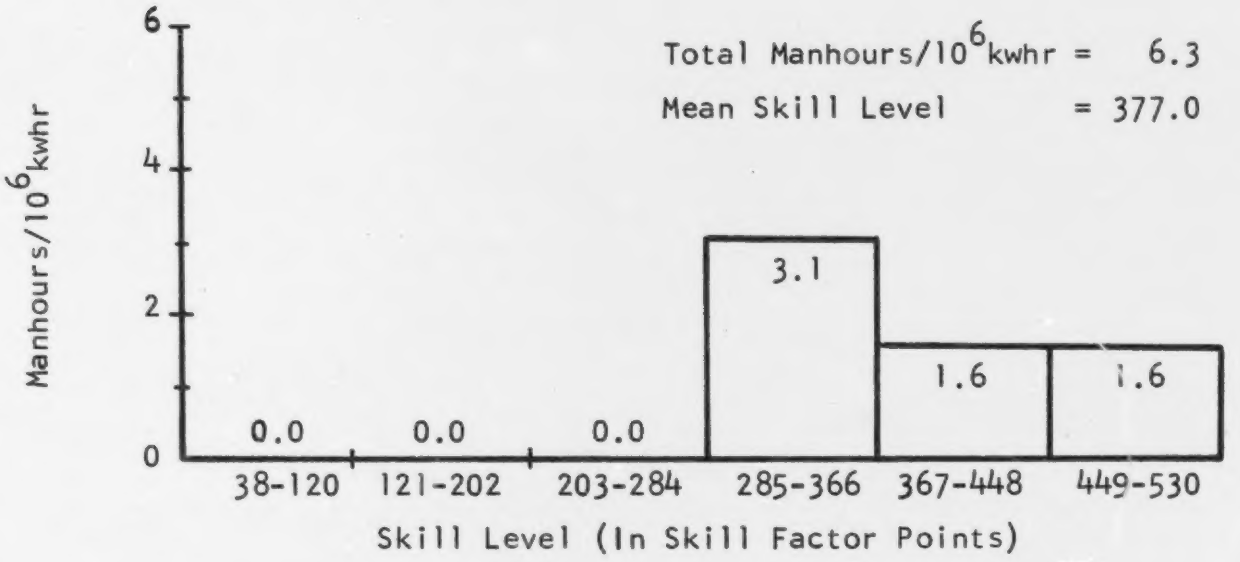
FIGURE 6.1: DIRECT LABOR SKILL PROFILES - POWER PLANTS IN UTILITY J

(a) Basis: 10^6 kwhr

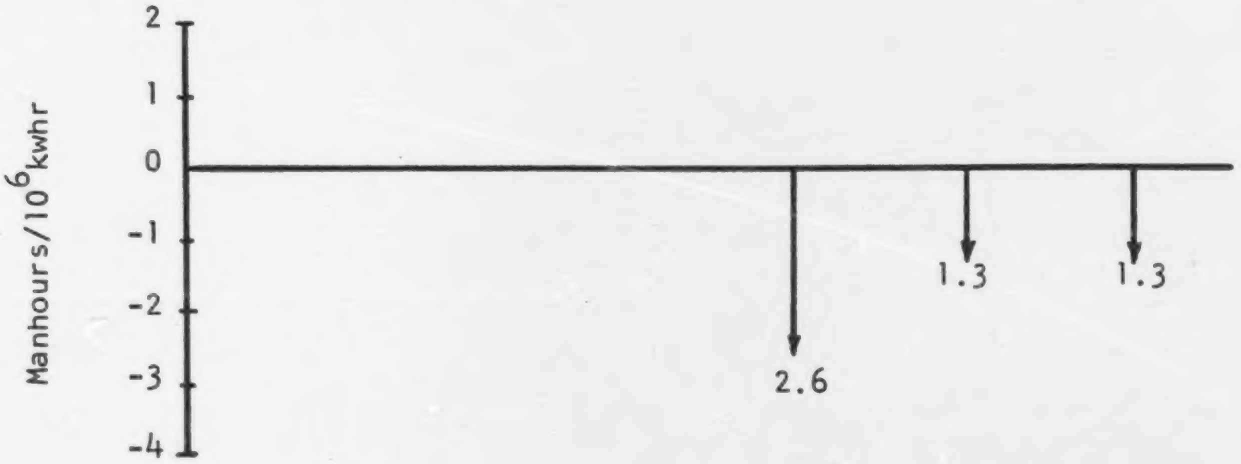
CENTRALIZED CONTROL



CENTRALIZED/COMPUTERIZED CONTROL

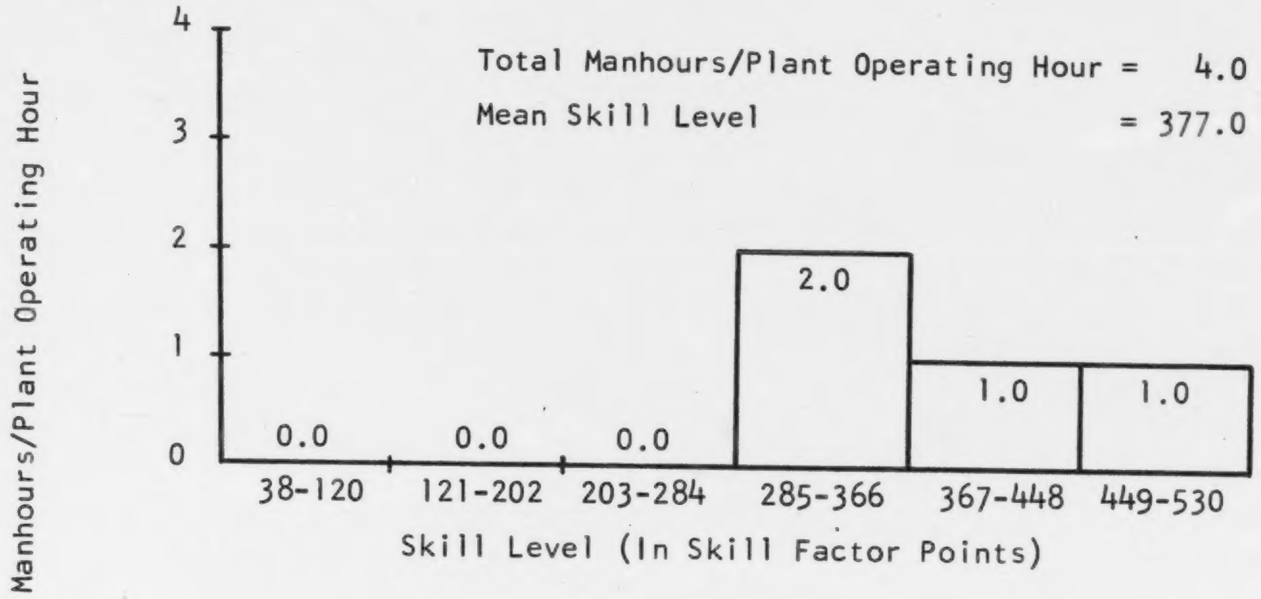


CHANGES - OLD TO NEW TECHNOLOGY

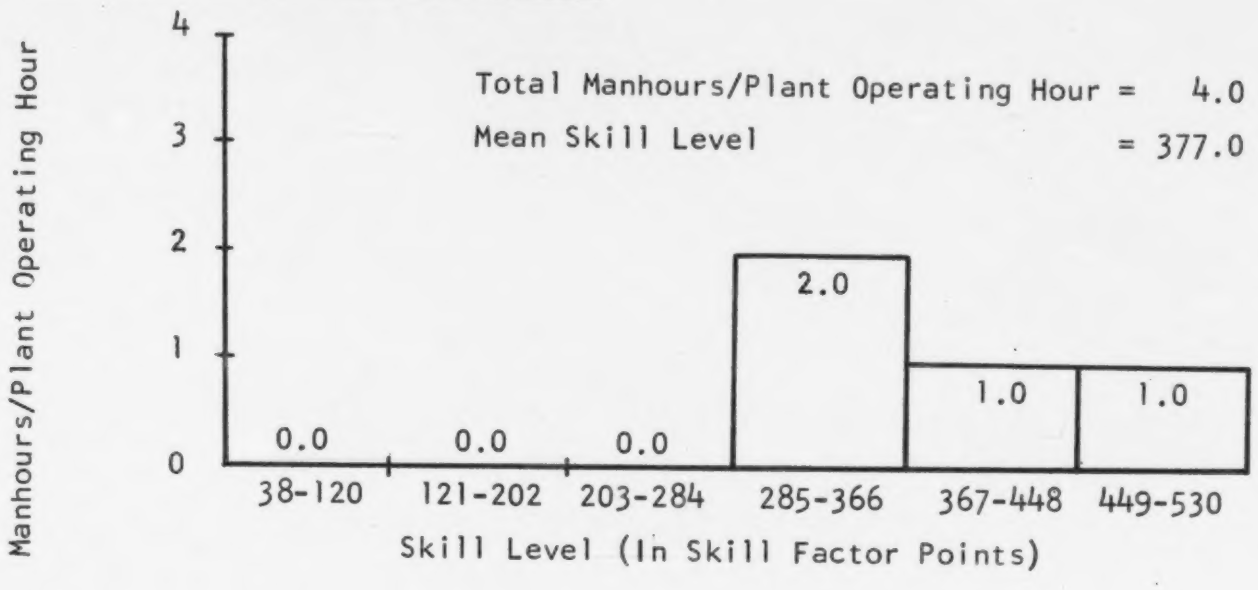


(b) Basis: Plant Operating Hour

CENTRALIZED CONTROL



CENTRALIZED/COMPUTERIZED CONTROL



CHANGES - OLD TO NEW TECHNOLOGY

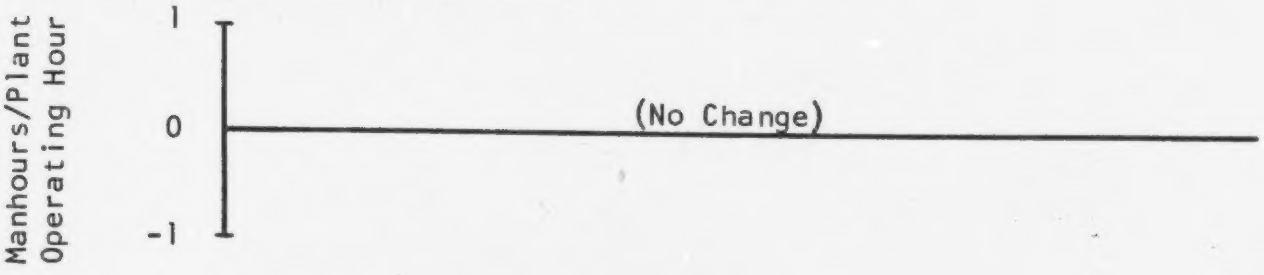


TABLE 6.3: DIRECT LABOR SKILL DISTRIBUTIONS FOR NON-COMPUTERIZED (TL2) AND COMPUTERIZED (TL3) POWER PLANTS IN UTILITY K

(a) Basis: 10^6 kwhr

Organization: Electric Utility K

Process: Power Production by Steam-Electric Process

Technology (Level 2): Centralized Control

Technology (Level 3): Centralized/Computerized Control

Source of Data: Direct Observation and Firm's Records

Period: Winter 1967

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10^6 kwhr			Manhours as % of Total for Technology Level			Number of Job Types		
		TL2	TL3	Change	TL2	TL3	Change	TL2	TL3	Change
High 6										
5	449-530	3.0	3.0	0.0	44.1	44.1	0.0	2	2	0
4	367-448	1.5	1.5	0.0	22.1	22.1	0.0	1	1	0
Medium 3	285-366	1.5	1.5	0.0	22.1	22.1	0.0	1	1	0
2	203-284	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Low 1	121-202	0.8	0.8	0.0	11.7	11.7	0.0	1	1	0
0	38-120	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	6.8	6.8	0.0	100.0	100.0	0.0	5	5	0
	Net Manhour Change 0.0%									

	Mean Skill Level	Standard Deviation
Technology (Level 2)	386.7	91.3
Technology (Level 3)	386.7	91.3
Change	0.0	

(b) Basis: Plant Operating Hour

Organization: Electric Utility K

Process: Power Production by Steam-Electric Process

Technology (Level 2): Centralized Control

Technology (Level 3): Centralized/Computerized Control

Source of Data: Direct Observation and Firm's Records

Period: Winter 1967

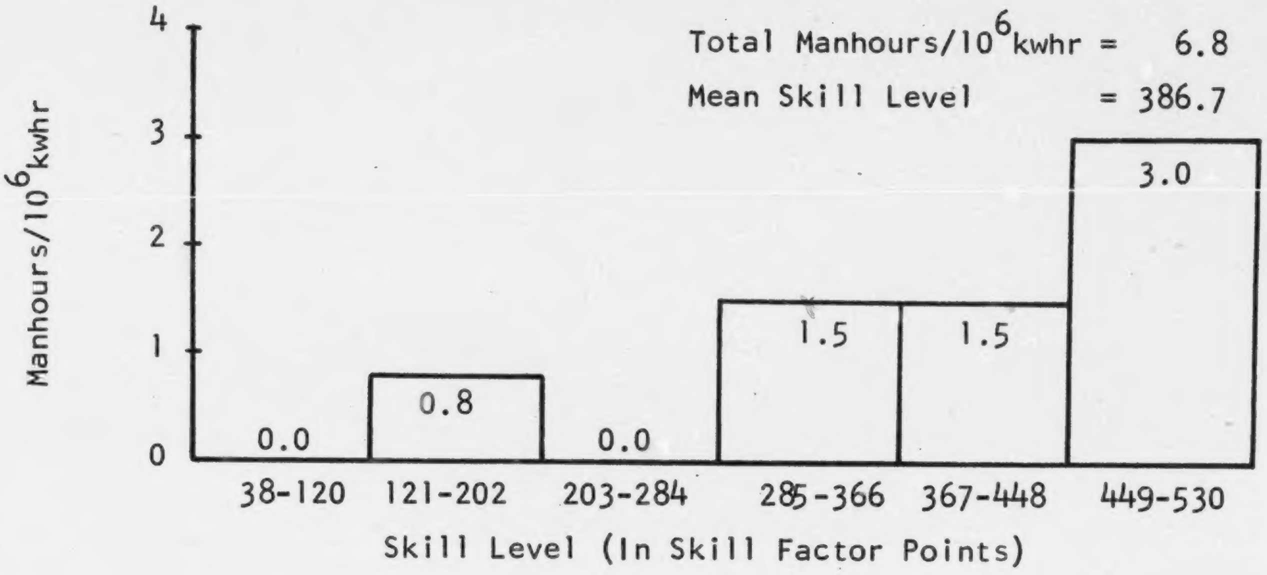
1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per Plant Operating Hour			Manhours as % of Total for Technology Level			Number of Job Types		
		TL2	TL3	Change	TL2	TL3	Change	TL2	TL3	Change
High 6										
5	449-530	2.0	2.0	0.0	44.5	44.5	0.0	2	2	0
4	367-448	1.0	1.0	0.0	22.2	22,2	0.0	1	1	0
Medium 3	285-366	1.0	1.0	0.0	22.2	22.2	0.0	1	1	0
2	203-284	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Low 1	121-202	0.5	0.5	0.0	11.1	11.1	0.0	1	1	0
0	38-120	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	4.5	4.5	0.0	100.0	100.0	0.0	5	5	0
	Manhour Change Due to Technology Change 0.0%									

	Mean Skill Level	Standard Deviation
Technology (Level 2)	386.7	91.3
Technology (Level 3)	386.7	91.3
Change	0.0	

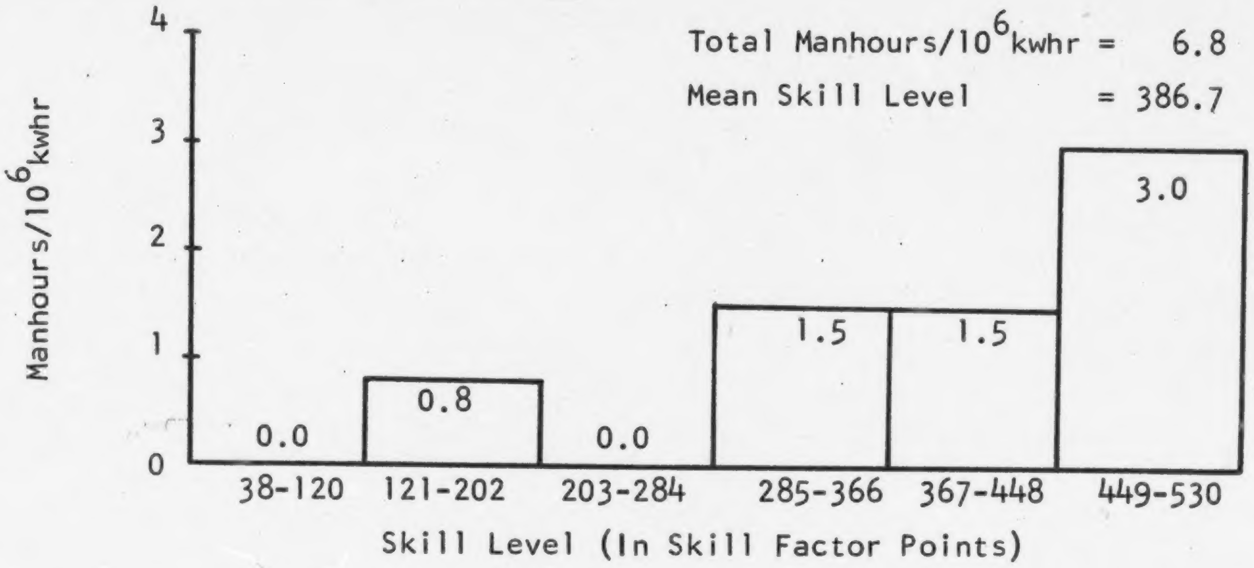
FIGURE 6.2: DIRECT LABOR SKILL PROFILES - POWER PLANTS IN UTILITY K

(a) Basis: 10^6 kwhr

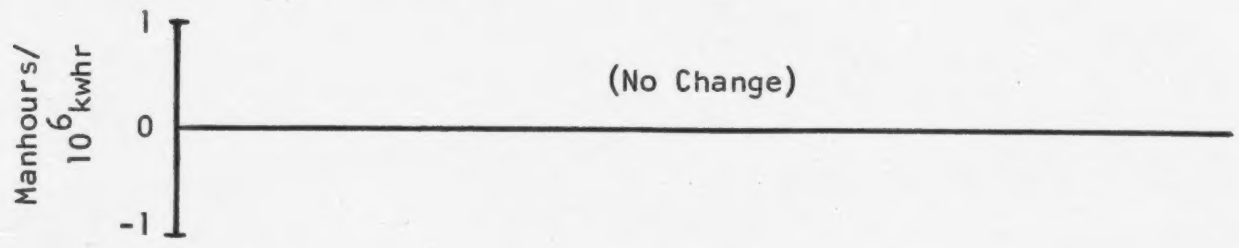
CENTRALIZED CONTROL



CENTRALIZED/COMPUTERIZED CONTROL

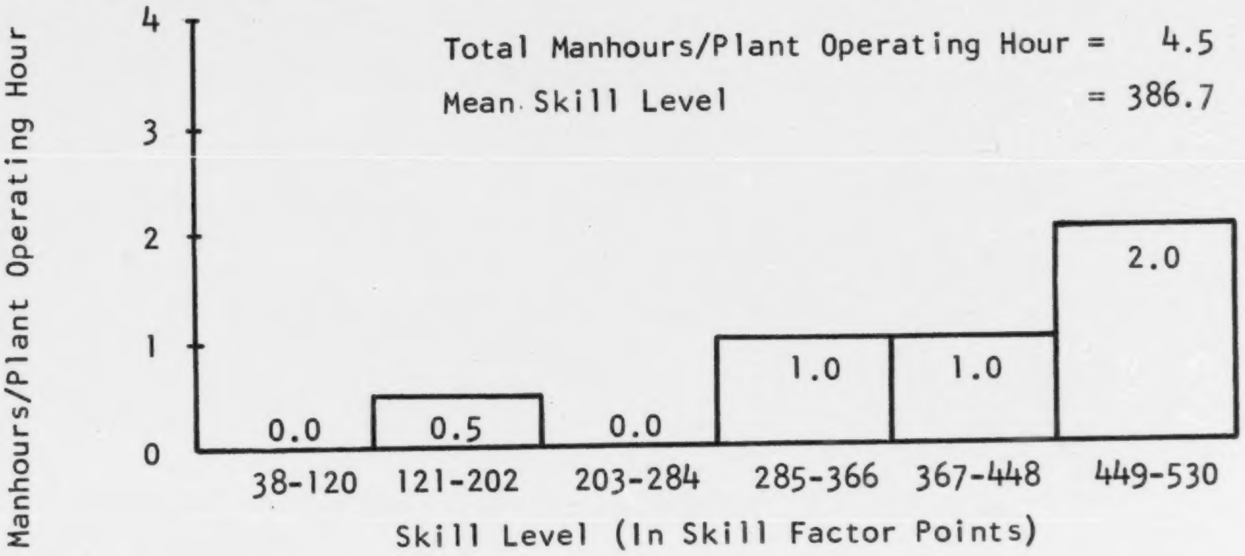


CHANGES - OLD TO NEW TECHNOLOGY

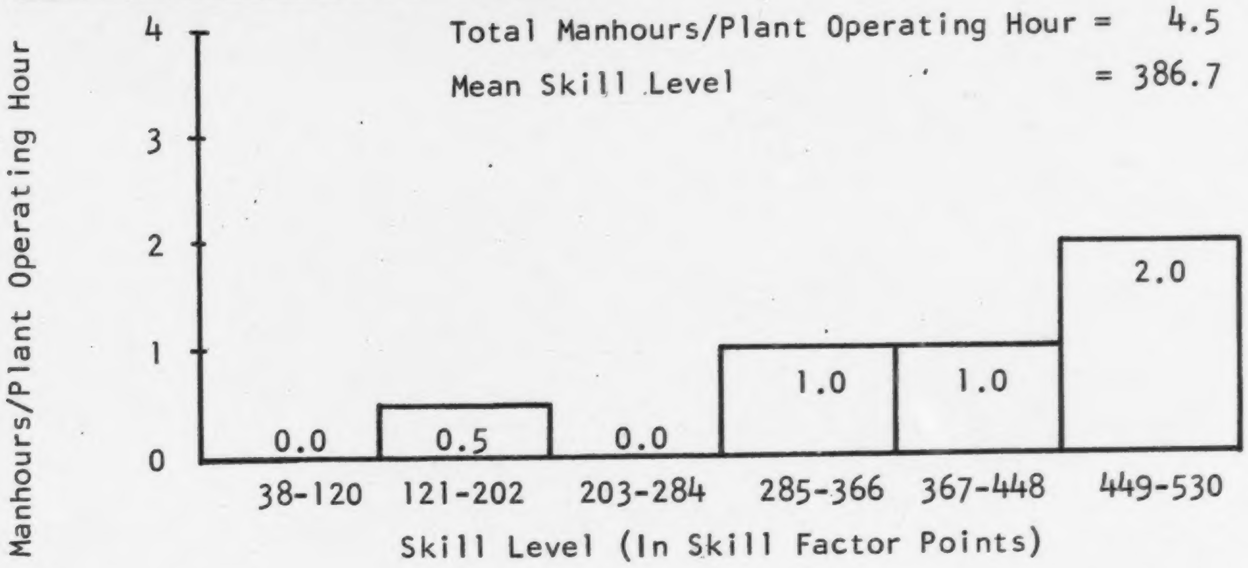


(b) Basis: Plant Operating Hour

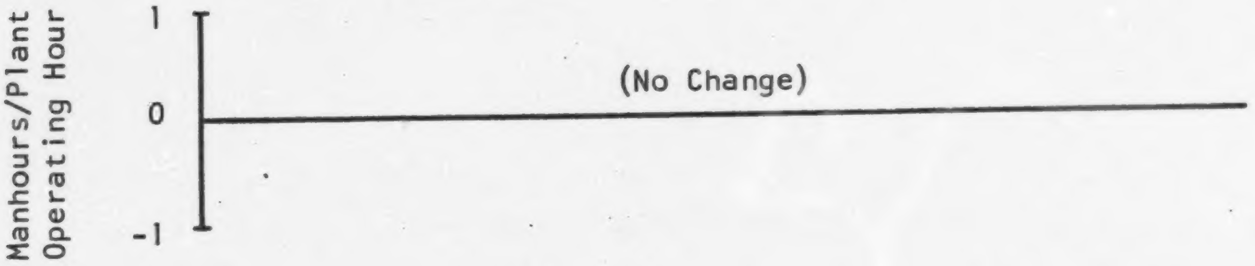
CENTRALIZED CONTROL



CENTRALIZED/COMPUTERIZED CONTROL



CHANGES - OLD TO NEW TECHNOLOGY



introduction of the process computer has left the manning pattern set up in the centralized Plant J2b unaffected, exactly as is the case with Plants K2 and K3. The decrease of 45.2% in total manhour requirements per unit kwhr found when the per unit product basis is used (Table 6.2a and Figure 6.1a), is purely a reflection of the difference in the capacities of Plants J2b (350 MW) and J3 (640 MW).

Changes in Skill Content

Installation of the computer left the individual job types in the operating crews as well as the number of job types unchanged in the plants of both utilities.

Changes in Educational and on-the-Job Experience Requirements

As shown in Tables 6.4 and 6.5 there has been no change in either the estimated general educational or the estimated on-the-job training requirements in Plants J3 and K3 as compared with Plants J2b and K2.

Indirect Labor Requirements in Plants J2b and J3

Data collection on indirect labor requirements was confined to Plants J2b and J3 whose organization corresponds broadly to that shown in Figure 5.6. The organizational pattern represented in the figure was designed to meet the exigencies of plants operating "unit" rather than "header" systems, and thus applies specifically to the two plants discussed in this section. Centralization of control in itself played a minor part, if any, in the reorganization, the main feature of which is the functional separation of day-to-day maintenance duties,allocated to small station crews, from larger overhaul and repair tasks performed by Divisional Maintenance squads.

A summary of maintenance manhours and mean skill levels is given in Table 6.6 on page 90. More detailed breakdowns of these manhours prorated to unit output (10^6 kwhr) and to plant operating hours is contained in the Tables C-6a and C-6b and Figures C-14a and C-14b in Appendix C, Section 9.

The smaller per unit manhour requirements of Plant J3 are exclusively ascribable to this plant's larger capacity, which is of secondary importance in the present context. This also holds good for the 20% increase in per plant manhour requirements, which have to do with the greater complexity of the operating equipment in this plant rather than with the installation of process computers. The 4% difference in mean skill levels of the maintenance force is too small even to approach statistical significance.

TABLE 6.6: CHANGES IN MAINTENANCE MANHOURS AND SKILL REQUIREMENTS

Plant	Control	System	Capacity (MW)	Manhours Per 10^6 kwhr	Manhours Per Plant	Mean Skill Level	No. of Job Types
J2b	Centralized	Unit	350	13.3	4.7	274.3	17
J3	Computerized	Unit	640	8.8	5.7	263.8	17

Supervisory manhours per plant operating hour increased very slightly in Plant J3 due to the creation of the position of Supervisor of Instrumentation, whose duties are exclusively in the area of computer maintenance.

Effects of Part-Computerized Process Control on the Total Labor Force

The consolidated results of the studies of direct and indirect labor requirements in Plants J2b and J3 are shown in Figures 6.3a and 6.3b. It will be immediately noted that in contrast to the small increase in manhour requirements when these are related to plant operating hour (Figure 6.3b), the use of unit product, 10^6 kwhr, as a basis indicates a very marked decrease in manhours (Figure 6.3a). This decrease, as previously emphasized, is wholly the outcome of increased plant size and hence generating capacity, and as such only of marginal interest in the present context, where the prime concern is with advances in control technology. These advances have evidently not caused significant changes in manhour requirements.

The above considerations also apply to Tables 6.7 and 6.8 which merely summarize for ease of review of the data in Figures 6.3a and 6.3b.

The limited transfer of some control functions to the computer has clearly left the manhour inputs almost unaffected. There was no significant change either in the skill requirements, as shown in Table 6.9 and by the shapes of the skill profiles in Figures 6.3a and 6.3b.

TABLE 6.9: AGGREGATE CHANGES IN DIRECT AND INDIRECT LABOR SKILL REQUIREMENTS

	TL2	TL3	% Change
Direct Labor	377.0	377.0	0.0
Maintenance	274.3	263.8	-4.4
Supervision	480.6	485.0	+0.01
All Labor	347.2	336.7	-3.4

TABLE 6.4: BEFORE AND AFTER COMPUTERIZATION ESTIMATED HIGH SCHOOL EDUCATION REQUIREMENTS, POWER GENERATION, FIRMS J AND K

High School Education (Years)	Average Manhours Per Plant Operating Hour			Average Manhours as % of Total for Each Technology Level		
	TL2	TL3	Change	TL2	TL3	Change
3 - 4	4.3	4.3	0.0	100.0	100.0	0.0
1 - 2	0.0	0.0	0.0	0.0	0.0	0.0
0	0.0	0.0	0.0	0.0	0.0	0.0

Mean Educational Level	TL2	TL3
(Years of High School)	3.5	3.5

TABLE 6.5: BEFORE AND AFTER COMPUTERIZATION ESTIMATED ON-THE-JOB EXPERIENCE REQUIREMENTS, POWER GENERATION, FIRMS J AND K

On-the-Job Experience (Months)	Average Manhours Per Plant Operating Hour			Average Manhours as % of Total for Each Technology Level		
	TL2	TL3	Change	TL2	TL3	Change
78 - 114	1.5	1.5	0.0	34.9	34.9	0.0
54 - 77	1.0	1.0	0.0	23.2	23.2	0.0
24 - 53	1.5	1.5	0.0	34.9	34.9	0.0
12 - 23	0.0	0.0	0.0	0.0	0.0	0.0
0 - 11	0.3	0.3	0.0	7.0	7.0	0.0

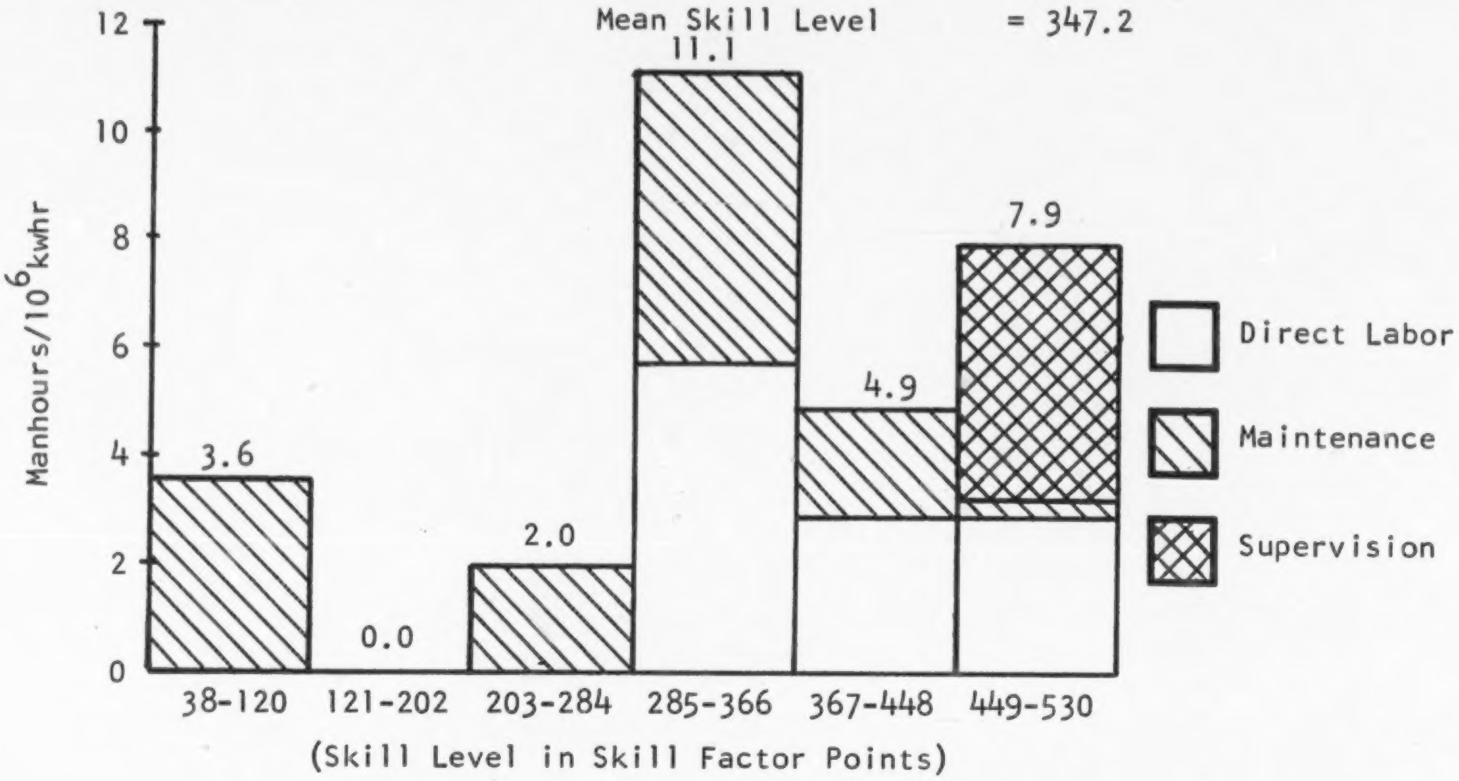
Mean Length of Experience	TL2	TL3
(Months)	62.5	62.5

FIGURE 6.3: COMPOSITE SKILL PROFILES FOR TOTAL LABOR FORCE IN POWER PLANTS J2b (NON-COMPUTERIZED) AND J3 (COMPUTERIZED)

(a) Basis: 10^6 kwhr

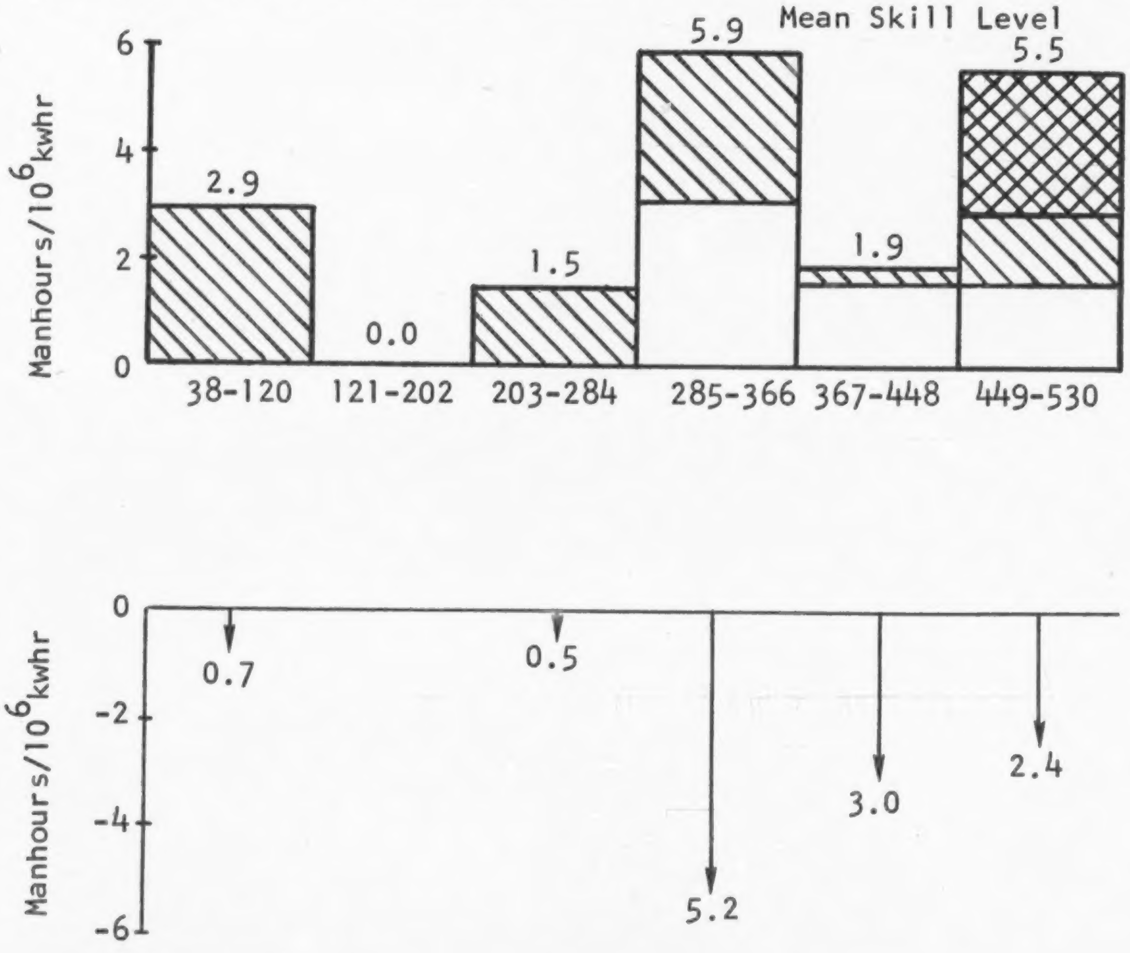
CENTRALIZED CONTROL

Total Manhours/10^6kwhr = 29.5
Mean Skill Level = 347.2

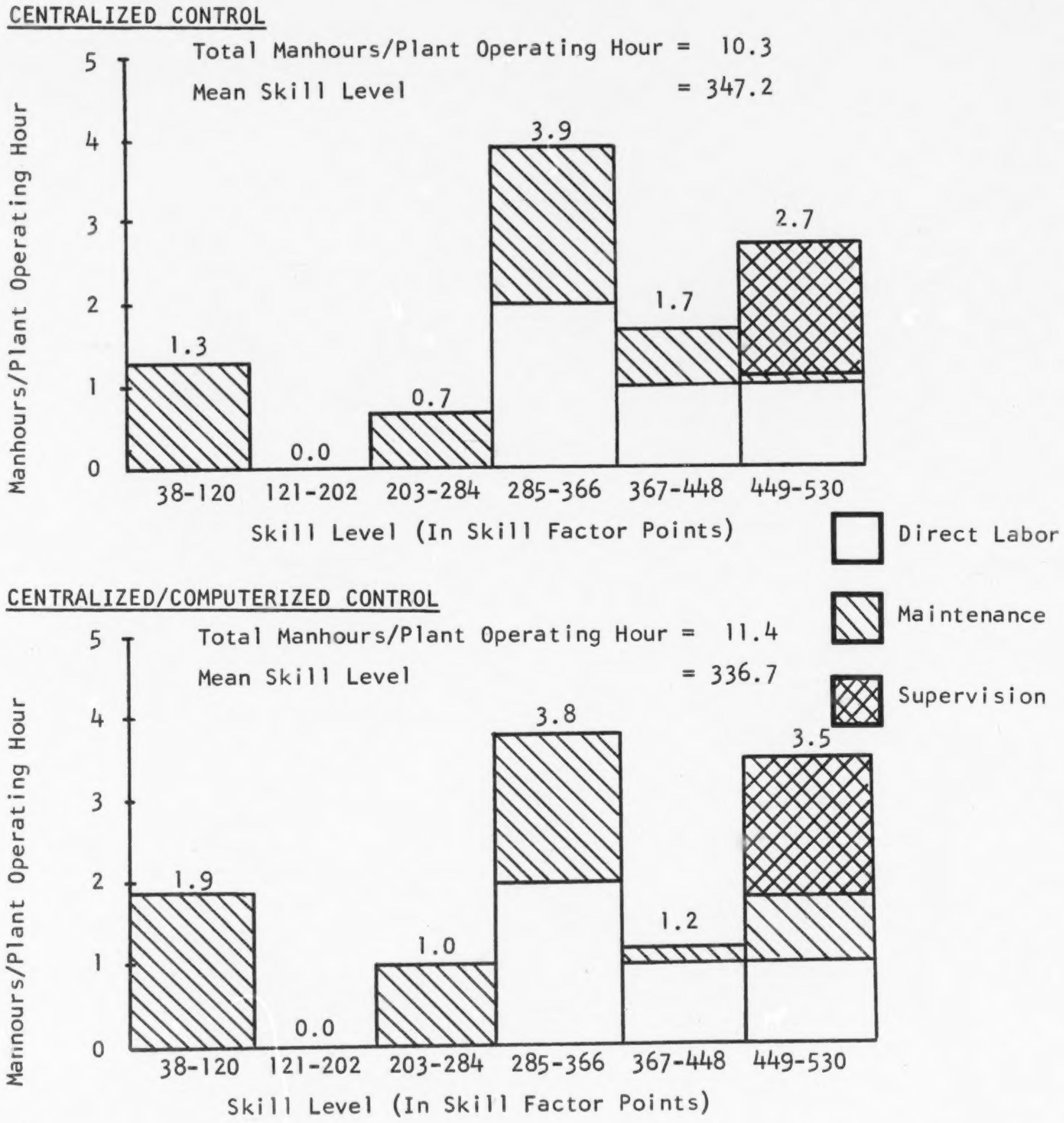


CENTRALIZED/COMPUTERIZED CONTROL

Total Manhours/10^6kwhr = 17.7
Mean Skill Level = 336.7



(b) Basis: Plant Operating Hour



CHANGES - OLD TO NEW TECHNOLOGY

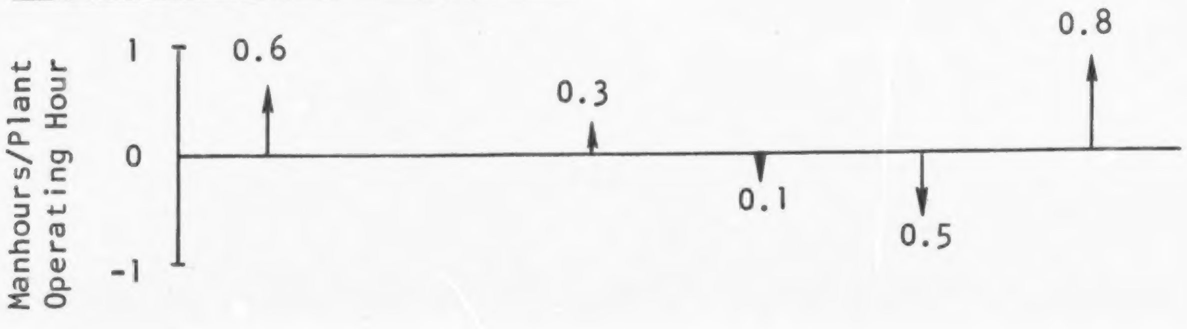


TABLE 6.7: AGGREGATE CHANGES IN DIRECT AND INDIRECT LABOR REQUIREMENTS (BASIS: 10^6 kwhr)

	Manhours Per 10^6 kwhr			Manhours as % of Total for Each Technology Level	
	TL2	TL3	% Change	TL2	TL3
Direct Labor	11.4	6.2	-45.6	38.5	35.0
Indirect Labor	18.1	11.5	-36.5	61.5	65.0
Maintenance	13.3	8.9	-33.1	45.2	50.0
Supervision	4.8	2.6	-45.8	16.3	15.0
Clerical	small	small	small	small	small
Totals	29.5	17.7	-40.0	(100)	(100)

TABLE 6.8: AGGREGATE CHANGES IN DIRECT AND INDIRECT LABOR MANHOUR REQUIREMENTS (BASIS: PLANT OPERATING HOUR)

	Manhours Per Plant Operating Hour			Manhours as % of Total for Each Technology Level	
	TL2	TL3	% Change	TL2	TL3
Direct Labor	4.0	4.0	0.0	38.5	35.0
Indirect Labor	6.4	7.4	+15.9	61.5	65.0
Maintenance	4.7	5.7	+21.3	45.2	50.0
Supervision	1.7	1.7	+0.01	16.3	15.0
Clerical	small	small	small	small	small
Totals	10.4	11.4	+ 9.6	(100)	(100)

6.3 Process Computers in Hydrocarbon Catalytic Cracking (Oil Refinery Application)

Process Description*

Since 1913 when the thermal cracking process was introduced commercially, technological change has become the way of life of the petroleum industry. This new process enabled the small yield of straight-run gasoline, resulting from the original simple distillation of crude oil in so-called tank and later pipe stills, to be augmented by converting the heavier distillates or fractions, previously used as fuel oils, into additional gasoline. Not only did the yield per barrel of crude rise to near 25%, but the synthetic gasoline also proved better suited for use in internal combustion engines.

Catalytic cracking introduced in the Thirties enabled the yield to be raised to not far short of 50%, but theoretically even higher yields appeared possible. The commercial exploitation of catalytic cracking processes in the industry generally was from the start contingent on automatic control and on instrumentation; there was an early realization that, second only to advances in catalyst technology, progress in automatic control would henceforth be the main factor in improving the yield and also the quality of marketable product. Of the very large sums expended by the industry in research and development, a substantial proportion has accordingly gone for some time past into automatic control technology.

At present there seem to be four areas where research and experimentation are mainly concentrated:

1) End-point control: The gearing of plant controllers' set-points to the desired qualities of the end product rather than to operating characteristics.

2) Open and closed-loop computer control: The calculation of the desired values of plant variables based on an optimizing computer control program, and the computer control of these variables by the adjustment of controller set-points.

3) Direct digital computer control: The direct inputting of process information recorded by the plant sensor elements into an electronic computer, and the direct activation of control elements by the computer through its output channels.

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*This section gives an overview of the technological change. For specifics of plant and process see Appendix D.

4) Centralized computer control: The setting up of an integrated computer installation controlling a number of process plants or all process plants comprising a refinery.

All of these developments involve the use of electronic digital computers, and catalytic crackers are a favorite site for their initial application. Of the ninety process computers reported to have been installed, or to be in the process of installation, in oil refineries throughout the world at the end of 1966, twenty-two were in catalytic cracking plants. This made these plants a suitable selection for the present studies.

Figure 6.4 indicates the location of the catalytic cracking unit in relation to the other process units in a diversified oil refinery. The diagram also provides some notion of the importance of the catalytic cracking unit in the sense that it shows how its component outputs serve as inputs of various auxiliary processes. The two levels of technology considered were manual as against partially computer initiated and maintained closed-loop process control. These two levels of control technology are briefly discussed below, a more detailed description is given in Appendix D, Section 1.

Control before and after Computerization

At the older technological level, most of the hundred odd process variables requiring regulation were controlled by automatic devices built into the plant. The operators carried out most functions from a control room equipped with display panels containing various recording and control instruments. Even though the job descriptions do not indicate much of a functional differentiation especially in the F.C.C.* units, each operator was responsible for a certain section of the unit in terms of its associated instruments. Due to the complexity of the process, the activities of the operators were highly interrelated since more than one operator was responsible for controlling different independent variables determining the values of the same dependent variables.

The control activities of the operators mainly consisted in adjusting the set-points of the various controllers so as to maintain optimal operating conditions for the unit. This meant frequent readjustments of each set-point because of disturbances from various sources, as well as from time-lags inherent in the process.

At the newer technological level the computer has assumed control of a small number of the more critical process variables

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*F.C.C. = Fluid Catalytic Cracker
T.C.C. = Thermofor Catalytic Cracker

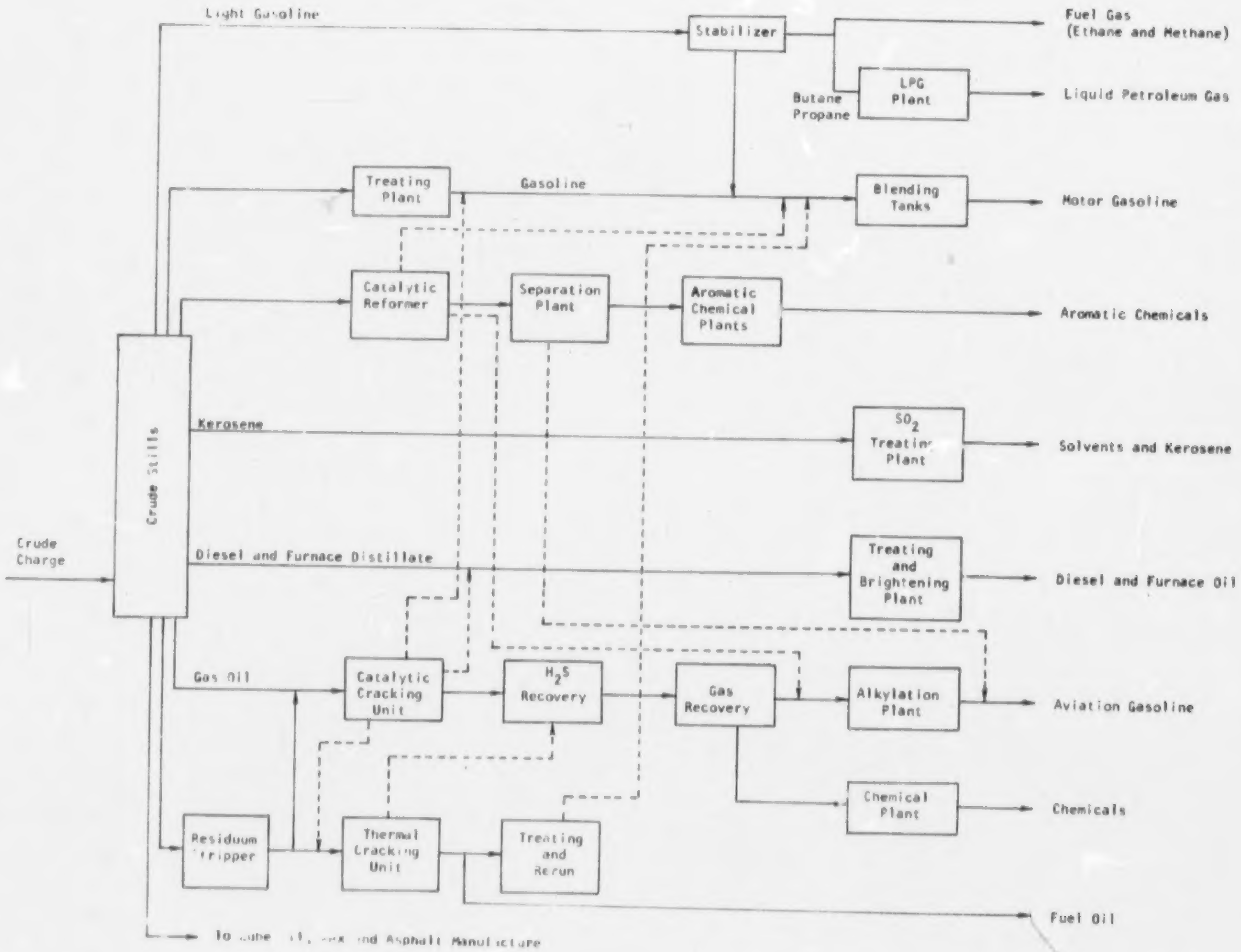
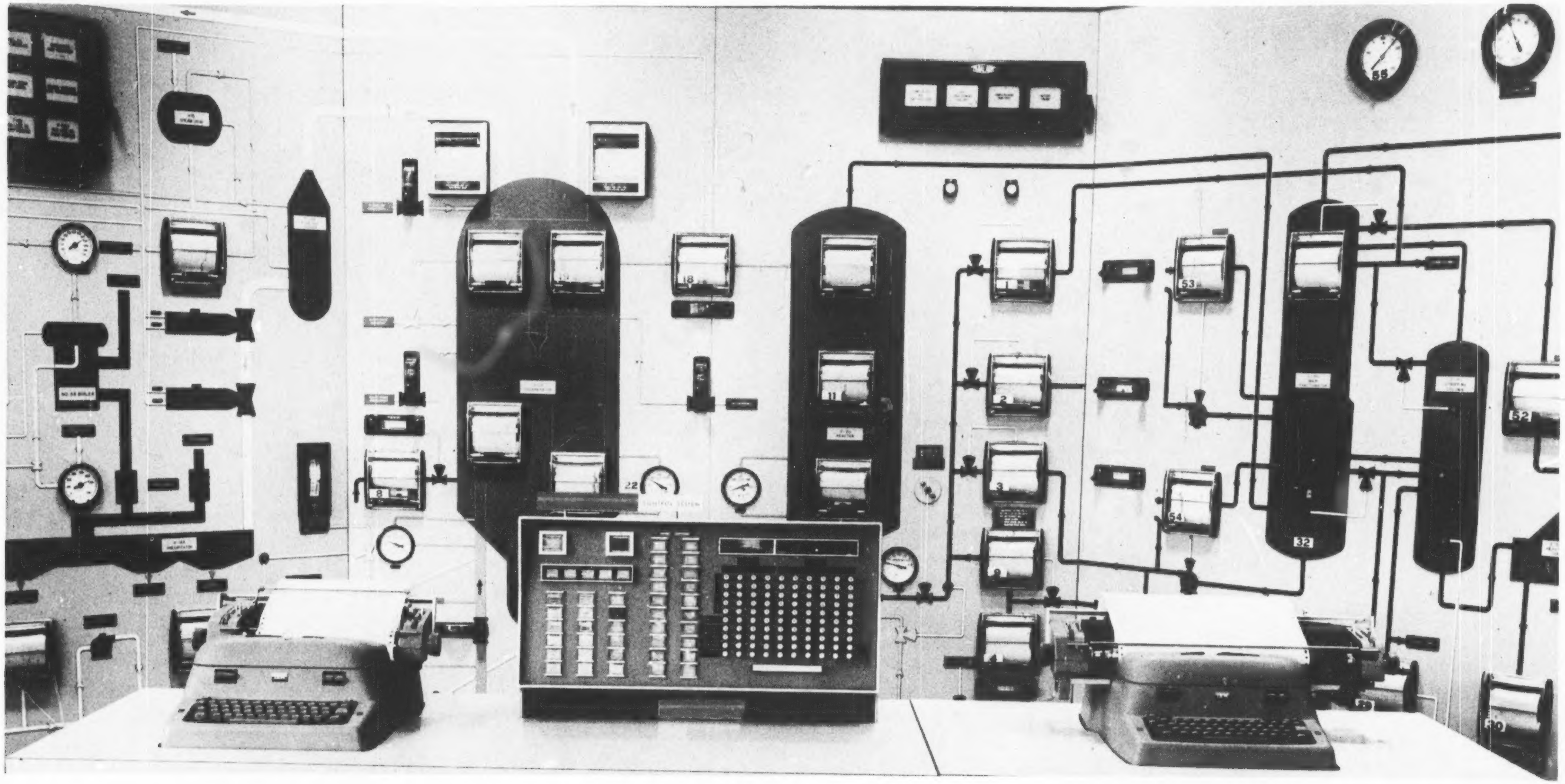

Crude Charge
Crude Stills
Light Gasoline
Stabilizer
Fuel Gas (Ethane and Methane)
Butane Propane
LPG Plant
Liquid Petroleum Gas
Treating Plant
Gasoline
Blending Tanks
Motor Gasoline
Catalytic Reformer
Separation Plant
Aromatic Chemical Plants
Aromatic Chemicals
Kerosene
SO2 Treating Plant
Solvents and Kerosene
Diesel and Furnace Distillate
Treating and Brightening Plant
Diesel and Furnace Oil
Gas Oil
Catalytic Cracking Unit
H2S Recovery
Gas Recovery
Alkylation Plant
Aviation Gasoline
Chemical Plant
Chemicals
Residuum Stripper
Thermal Cracking Unit
Treating and Rerun
Fuel Oil
To Lube Oil, Wax and Asphalt Manufacture

FIGURE 6.4: SCHEMATIC DIAGRAM OF A TYPICAL OIL REFINERY

ILLUSTRATION 6.1: CENTRAL CONTROL ROOM OF A FLUID CATALYTIC CRACKING UNIT (FIRM G)

The graphic panel incorporates a process flow diagram showing the relative location of the various controlling and measuring instruments and the different product streams between plant components. The equipment on the table is part of the computer installation.



influencing product value and conversion*. When operating in the closed-loop mode the computer through its control program adjusts the set-points of the controllers associated with these variables and maintains close to optimal operating conditions over long periods of time. Computer control is significantly smoother, since several set-points can be changed simultaneously and there is thus hardly any time lag between the control-program recommendations and changes in the set-points.

Aside from the occasions when the computer assumes direct control over some plant variables, it is permanently available as an aid to operators, for whom it prints out recommended settings for several of the manually controlled variables as calculated by its optimizing control program. Through the scan and alarm programs, the computer also detects and informs the operator of any malfunctioning of instruments. A logging program finally provides the operator with information on process variables at predetermined intervals or on demand. All this information is presented to the operator in typewritten message form.

Three modes of control may be selected by the operating crew under the newer technology:

Manual Control - This is the same as the older technological level, i.e., operator receives no aid from the computer.

Open-Loop Control - The computer does not control any of the process variables, but prints out an "operating guide" that provides the operator with recommended settings for several of the controllable variables, based on values derived from the optimizing control program.

Closed-Loop Control - Besides providing the operator with an "operating guide," the computer exercises direct control over a small number of process variables by changing the set-points of the controller associated with these variables.

On the two F.C.C. units, closed-loop, open-loop and manual control are used an estimated 85, 5 and 10% of the time respectively; the corresponding percentages for the T.C.C. unit are 90, 0 and 10. Even though it would be possible to operate the units for more than 85-90% of the time in the closed-loop mode, it is at present felt by the supervisors that the system should be retained for about 10-15% of the time on manual control in order to prevent operators becoming "rusty" and relying too heavily on the computer.

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*As used in this report, product value is the dollar value of process output less the value of plant feed required to produce this output. Conversion is the yield of lighter fractions (i.e., gasolines, etc.) per unit of the fresh feed.

Effect of Computer Control on Production

For competitive reasons, the firms concerned were understandably not prepared to provide data on the output of their catalytic cracking units, which would necessarily reveal their success in achieving increased yield of the commercially most valuable lighter fraction products. Furthermore, improvements in the catalyst and in instrumentation not necessarily associated with the computer installation would make it difficult to isolate the change in yield due to the introduction of closed-loop computer control. For these reasons, the input of gas oil into the three cracking units was used to derive the skill profiles. This variable, which is determined by the plant throughput capacity and thus essentially remains fixed within a range of ± 10% (in terms of barrels per day), is insensitive to improvements in the efficiency of the conversion process.

Though it has not been possible to assess quantitatively what production gains have been made through the introduction of process control computers in the three refineries, it was stated by management that in addition to the valuable operational experience which has accumulated from the use of the process computers to date, there have been definite production pay-offs. In one of the refineries it was stated that the 2% rise in product value hoped for at the time the computer was installed, had been substantially exceeded.* This can only mean that the average yield of the lighter fractions has increased, a result which is the outcome of tighter control that permits the unit to be operated closer to its critical limits. However, throughput capacity was unaffected by computerization.

Changes in Direct Labor Manpower and Skill Requirements

The crews in the control room of all three cracking units were the same before and after the technological change and worked the same hours. Some reductions in per unit labor requirements consequent on the computerization of the catalytic cracking units would only have appeared if these requirements could have been related to changes in the yield of gasoline. Related to 1000 barrels of gas oil input, the manpower requirements were unchanged (see Figures 6.5, 6.6 and 6.7).

From the description of the operational procedures in the control room in a preceding section, it appears that the activities of the crew were not materially affected by the introduction of the computer. This observation receives confirmation from a comparison of the results of activity analyses, carried out in one of the refineries shortly before computerization and again recently, after the computer had become thoroughly established. Summaries of these

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*Even a small percent increase in product value represents a major economic gain due to the large throughput.

TABLE 6.10: DIRECT LABOR SKILL DISTRIBUTIONS FOR PRE-COMPUTERIZED (TL1) AND POST-COMPUTERIZED (TL2) CONTROL OF F.C.C. UNIT IN REFINERY G.

Organization: Oil Refinery G

Process: Fluid Catalytic Cracking Product Unit: 1000 Barrels

Technology (Level 1): Pre-Computerization

Technology (Level 2): Post-Computerization

Source of Data: Direct Observation

Period: Spring 1967

1		2	3	4	5	6	7	8	9	10	11
Skill Level		Skill Point Range	Manhours Per 1000 Barrels			Manhours as % of Total for Technology Level			Number of Job Types		
			TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High	6	396-461	0.9	0.9	0.0	29.0	29.0	0.0	2	2	0
	5	330-395	2.2	2.2	0.0	71.0	71.0	0.0	5	5	0
	4	264-329	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Medium	3	198-263	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	2	132-197	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Low	1	66-131	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	0										
		Totals	3.1	3.1	0.0	100.0	100.0	0.0	7	7	0
		Net Manhour Change 0.0%									

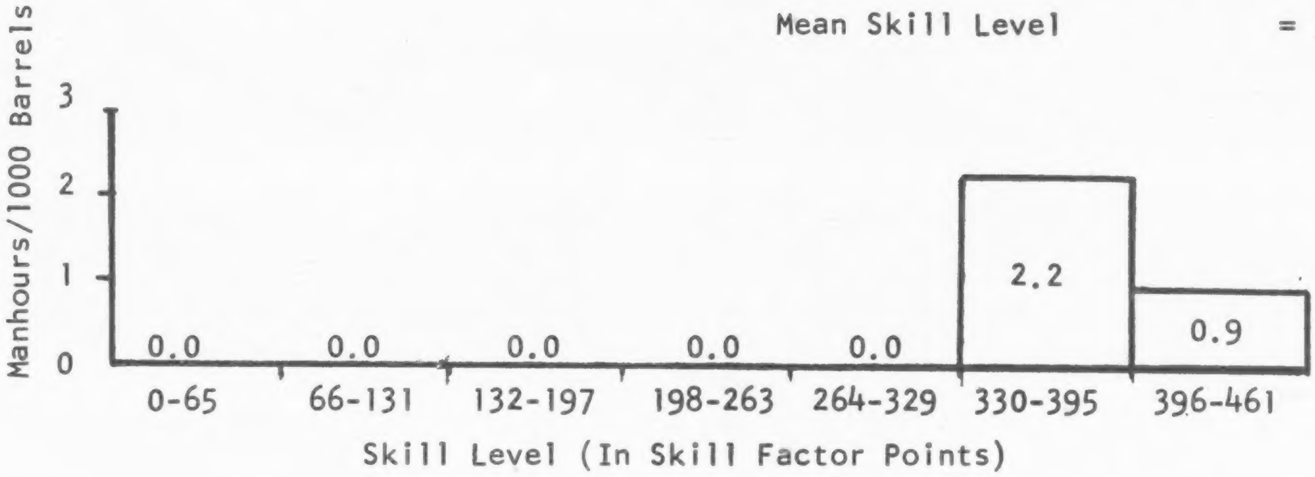
	Mean Skill Level	Standard Deviation
Technology (Level 1)	368.6	17.6
Technology (Level 2)	368.6	17.6
Change	0.0	

FIG. 6.5: DIRECT LABOR SKILL PROFILES F.C.C. UNIT IN REFINERY G.

F.C.C. PRE-COMPUTERIZATION

Total Manhours/1000 Barrels = 3.1

Mean Skill Level = 368.6



F.C.C. POST-COMPUTERIZATION

Total Manhours/1000 Barrels = 3.1

Mean Skill Level = 368.6

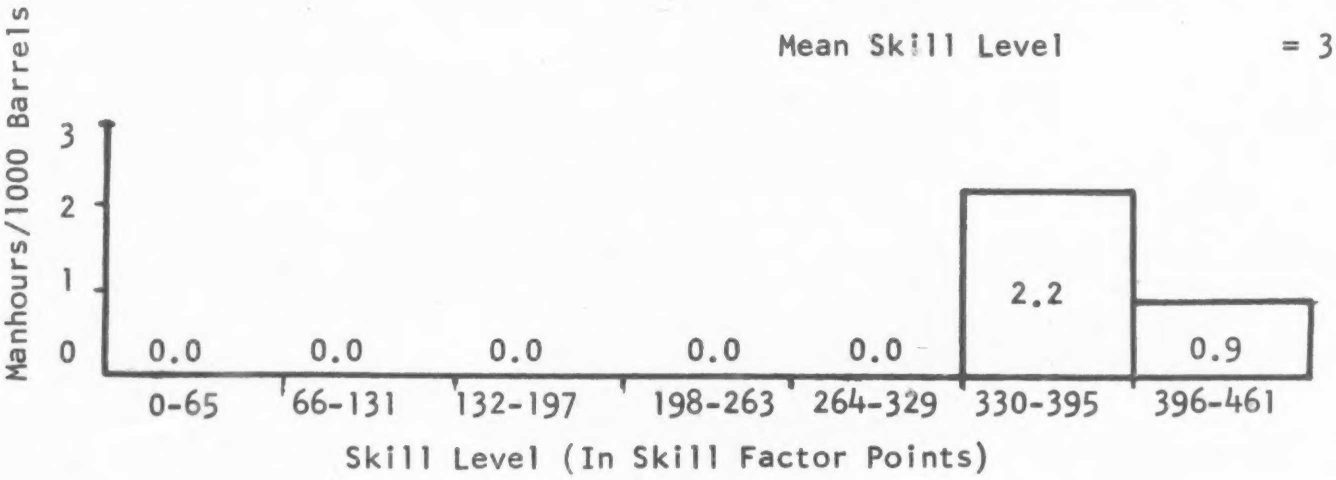


TABLE 6.11: DIRECT LABOR SKILL DISTRIBUTIONS FOR PRE-COMPUTERIZED (TL1) AND POST-COMPUTERIZATION (TL2) CONTROL OF F.C.C. UNIT IN REFINERY H.

Organization: Oil Refinery H

Process: Fluid Catalytic Cracking Product Unit: 1000 Barrels

Technology (Level 1): Pre-Computerization

Technology (Level 2): Post-Computerization

Source of Data: Direct Observation

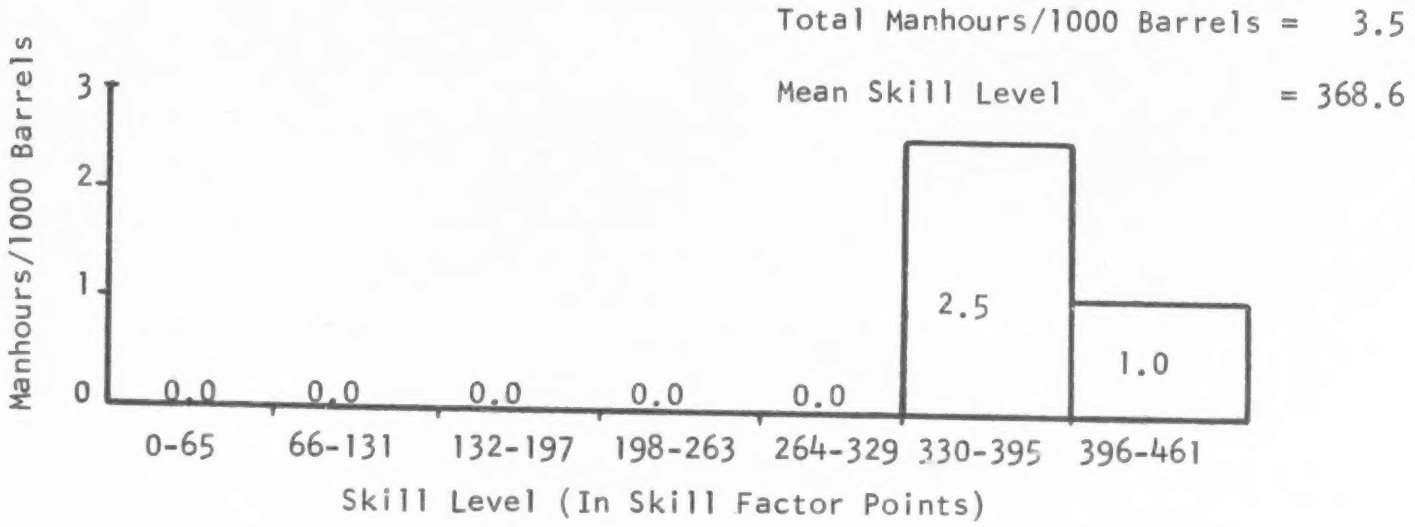
Period: Spring 1967

1		2	3	4	5	6	7	8	9	10	11
Skill Level		Skill Point Range	Manhours Per 1000 Barrels			Manhours as % of Total for Technology Level			Number of Job Types		
			TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High	6	396.461	1.0	1.0	0.0	28.6	28.6	0.0	2	2	0
	5	330-394	2.5	2.5	0.0	71.4	71.4	0.0	5	5	0
	4	264-329	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Medium	3	198-263	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	2	132-197	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Low	1	66-131	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	0	0- 65	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
		Totals	3.5	3.5	0.0	100.0	100.0	0.0	7	7	0
		Net Manhour Change 0.0%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	368.6	17.6
Technology (Level 2)	368.6	17.6
Change	0.0	

FIG. 6.6: DIRECT LABOR SKILL PROFILES F.C.C. UNIT IN REFINERY H.

F.C.C. PRE-COMPUTERIZATION



F.C.C. POST-COMPUTERIZATION

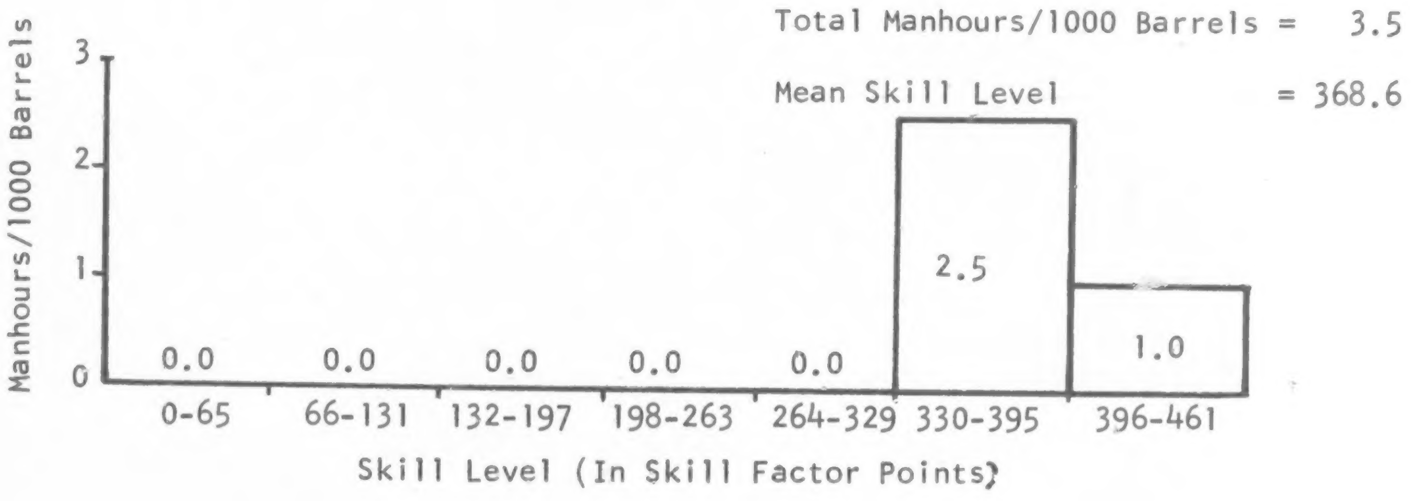


TABLE 6.12: DIRECT LABOR FORCE SKILL DISTRIBUTIONS FOR PRE-COMPUTERIZATION (TL1) AND POST-COMPUTERIZATION (TL2) CONTROL OF TCC UNIT IN REFINERY I.

Organization: Oil Refinery I

Process: Thermofor Catalytic Cracking Product Unit: 1000 Barrels

Technology (Level 1): Pre-Computerization

Technology (Level 2): Post-Computerization

Source of Data: Direct Observation

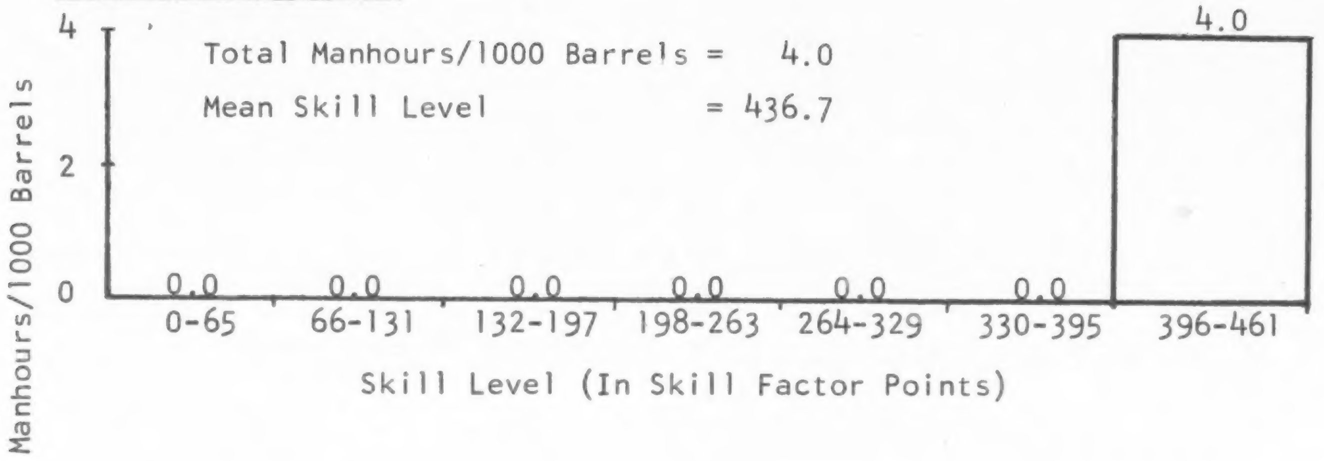
Period: Spring 1967

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 1000 Barrels			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6	396-461	4.0	4.0	0.0	100.0	100.0	0.0	3	3	0
5	330-395	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
4	264-329	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Medium 3	198-263	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
2	132-197	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Low 1	66-131	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0	0- 65	0.0	0,0	0.0	0.0	0.0	0.0	0	0	0
	Totals	4.0	4.0	0.0	100.0	100.0	0.0	3	3	0
	Net Manhour Change 0.0%									

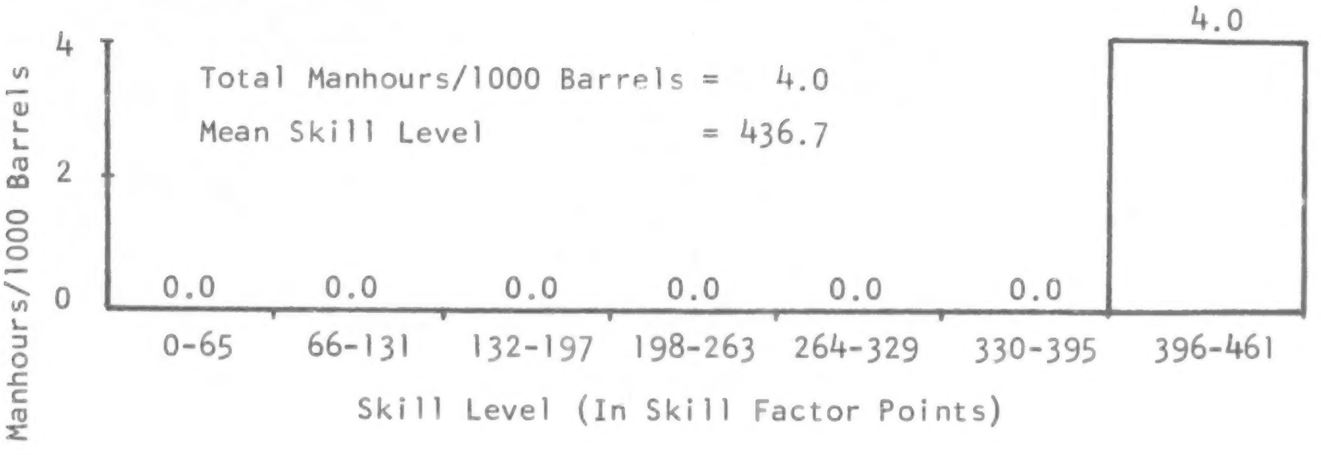
	Mean Skill Level	Standard Deviation
Technology (Level 1)	436.7	11.9
Technology (Level 2)	436.7	11.9
Change	0.0	

FIG. 6.7: DIRECT LABOR SKILL PROFILES--T.C.C. UNIT IN REFINERY I.

PRE-COMPUTERIZATION



POST-COMPUTERIZATION



results will be found in Section 5 of Appendix D. The original purpose of the activity analyses was to ascertain the workload on each operator with a view to its more equitable redistribution over the crew.

It will be noted that the total effective labor input by the whole operating crew as determined by the activity analysis has risen from 51% (142.5 hours) to 55% (156.0 hours) per week; none of the additional hours worked have gone into control and monitoring activities. The latter have actually decreased, both absolutely (from 100.5 hours to 94.5 hours per week) and as a percentage (from 35.9% to 33.6%). The very slight decrease in control and monitoring activities indicates that the impact of the computer on total labor input is not very marked.

Comparison of the labor inputs broken down by skill levels equally confirms little change in operational practices. Both before and after computerization the inputs are bunched about the highest values of the skill scale, most of the low skill-level work having been eliminated much earlier, when catalytic cracking displaced the older processes;* the small amount of this work which remains has been integrated into the operators main duties (this phenomenon is common to both catalytic processes studied, the Fluid and the Thermofor).

Indirect Labor

The indirect labor force on catalytic cracking installations--both Fluid and Thermofor--is made up of supervision and maintenance. On the F.C.C. units in the refineries studied there were two supervisors, a Plant Supervisor and a Section Shift Supervisor, who between them contributed about 5% of the total per unit manhours at either technology level. The Plant Supervisor is responsible for planning the operations of the cracking unit on the day shifts, the Section Shift Supervisor (who additionally oversees six other units in the Division) is in charge of the remaining shifts.

Maintenance which is provided by a separate department, accounted for around 12% of the total per unit manhour input on the computerless installations,and has increased to about 14% on the newer technology. Maintenance planning is also taking up more of the Supervisors' time, a good deal of it accounted for by the needs of the computer-associated equipment.

The overall per unit manhour requirements of the F.C.C. plants in Refineries G and H are shown in Table 6.13 and 6.14.

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*A detailed description of the changes attending the introduction of the newer cracking technology is given in U.S. Department of Labor, Bureau of Labor Statistics Report No. 120.

Supervision on the T.C.C. plant in Refinery I consisted of a Unit Foreman, and Assistant Foreman and a Shift Foreman. The activities of the first two correspond broadly to those of the F.C.C. Plant Supervisor, those of the Shift Foreman are equivalent in content to those of the F.C.C. Section Shift Supervisor. However, supervisory per unit manhours account for approximately 13% of the total per unit manhours at both technology levels, compared with 5% on the F.C.C. plants.

The maintenance complement on the T.C.C. plant was increased at the newer technology level, a second Instrument Mechanic concerned exclusively with the computer and its ancillary equipment being added to the Mechanic in charge of existing controllers and recorders.

Maintenance manhours per unit product also constituted a higher proportion of the total per unit manhours than on the F.C.C. plants, at both technology levels: 22% at TL1 (12% on the F.C.C. plants) and 27% at TL2 (14% on the F.C.C. plants). The increase from TL1 to TL2 is due to the second Maintenance Mechanic's manhours.

In toto, indirect labor appears to be much more prominent in the T.C.C. plant, where the ratio of indirect to direct manhours is 1:2, as against a ratio of 1:5 in the F.C.C. plants. The total per unit T.C.C. manhours are given in Table 6.15. In comparing the absolute per unit manhours with those on the two F.C.C. plants, allowance should be made for the fact that whereas the capacities of the latter are in the region of 17,000 barrels per shift, the T.C.C. plant's capacity is only 6,000 barrels per shift. If this were to be discounted, the total per unit manhours would be lower on the T.C.C. then the F.C.C. plants.

Changes in Educational and on-the-Job Experience Requirements

The tables in Appendix D, Section 4 give estimates of the length of on-the-job experience required of the various operators of the three catalytic cracking units. No specific educational requirements, such as number of years of high school education, were considered in evaluating the skill of the operators, even though the three firms formally required new prospective operators to have a high school education or equivalent. During interviews with personnel in the three firms, it was specifically mentioned by personnel in one of the firms that the operators did not require a high school education to perform their duties satisfactorily, and that such an educational requirement was mainly intended to qualify the operators for promotions.

No appreciable change in the on-the-job experience requirements occurred with the introduction of computer control. Even though none of the operators had previously been involved with computers, they were able to operate the computerized system after about two days of formal training. The fact that the skill ratings of the operators are determined mainly by on-the-job experience partly

	Manhours per 1000 Barrels			Manhours as % of Total for each Technology Level	
	TL1	TL2	% Change	TL1	TL2
Direct Labor	3.50	3.50	0	82.7	80.3
Indirect Labor	.73	.86	+18	17.3	19.7
Maintenance	.50	.63	+26	11.8	14.4
Supervision	.23	.23	0	5.5	5.3
Totals	4.23	4.36	+ 3	100	100

TABLE 6.13: AGGREGATE CHANGES IN DIRECT AND INDIRECT LABOR MANHOUR REQUIREMENTS F.C.C. PLANT, REFINERY G.

	Manhours per 1000 Barrels			Manhours as % of Total for each Technology Level	
	TL1	TL2	% Change	TL1	TL2
Direct Labor	3.10	3.10	0	83.1	80.7
Indirect Labor	.63	.74	+17	16.9	19.3
Maintenance	.44	.55	+25	11.8	14.3
Supervision	.19	.19	0	5.1	5.0
Totals	3.73	3.84	+ 3	100	100

TABLE 6.14: AGGREGATE CHANGES IN DIRECT AND INDIRECT LABOR MANHOUR REQUIREMENTS F.C.C. PLANT, REFINERY H.

explains why these ratings were found to be the same for the two levels of technology. It is interesting to note that in one of the firms the average length of actual experience of all men presently filling the jobs of Head Operator, Unit Operator and Operator is 23, 21 and 8 years, respectively, while the comparable figures for required experience were estimated as 9, 7 and 3.5 years only.

TABLE 6.15: AGGREGATE CHANGES IN DIRECT AND INDIRECT LABOR MAN-HOUR REQUIREMENTS, T.C.C. PLANT, REFINERY I

	Manhours Per 1000 Barrels			Manhours as % of Total for Each Technology Level	
	TL1	TL2	% Change	TL1	TL2
Direct Labor	4.00	4.00	0	64.9	60.5
Indirect Labor	2.16	2.61	+21	35.1	39.5
Maintenance	1.33	1.78	+34	21.6	26.9
Supervision	.83	.83	0	13.5	12.6
Totals	6.16	6.61	+ 7	100	100

6.4 Process Computers in Air Separation (Chemical Industry)

Process Description

Air separation on a commercial scale meets a growing demand for the separated components of atmospheric air, especially oxygen, nitrogen and argon. The process is a two-stage one, air being first liquefied and then fractionated. Liquefaction of air (or any other gas) is accomplished by first cooling to condensation temperature and then removing the latent heat of vaporization. Since condensation temperatures are very low (around -250°F), the central problem of air liquefaction is to find a refrigeration process that effectively removes heat from a substance already at low temperature. Most of the research effort put into modern liquefiers is concerned with finding efficient methods of production and conservation of refrigeration.

The idea that the components of liquid air could be separated by applying the well-known fractional distillation methods of the alcohol industry, was conceived by Linde and Hampson toward the end of the last century. They realized that such methods would ultimately make it possible to produce tonnage oxygen leading to new uses for the gas, and the development of a new industry to produce it.

With the discovery of new applications in steel making, welding and metal cutting, and in the field of medicine, and with the growing use of cryogenic propellants in space vehicles, demand for air products has been expanding at a startling rate over recent years. There has also been an increasing demand for purer products. The suppliers have responded by committing resources and directing effort to (1) low temperature research, (2) the development of more efficient methods and equipment for air separation and purification, and (3) the search for improved process-control equipment.

On the operational side, the original single column distillation unit in widespread use since 1902 is being replaced by multiple column arrangements. These new units enable the efficient production of both pure oxygen and pure nitrogen, where the older units only produced pure oxygen and impure nitrogen.

The control aspect of an air separation plant is a principal determinant of plant utilization, equipment efficiencies and qualities of end products. Even though these processes were not necessarily contingent on automatic control instrumentation, the development of such instruments found a logical application in air separation plants. Most modern plants employ conventional automatic control instruments, and only a few of the older and smaller plants are still entirely on manual operation. The aim for some time past has been, if not totally closed-loop, then at least partly closed-loop and partly open-loop computer control, with direct digital control as the ultimate objective.

Effects of Computer Control on Production

Due to reduced electric power consumption the computerized dual process plant is about 5-7% more efficient in the production of liquid oxygen and liquid nitrogen than an identical plant would be under conventional control. The yield of argon is also increased by as much as 10-15%. The reason for this is that in a manually controlled plant a very slight operator error may reduce argon purity to the point where production must be dumped. This never happens in the computerized plant. Moreover, it takes 12-14 hours before argon production is back to normal after dumping. Oxygen and nitrogen production is unaffected by stoppages in argon production.

Increases in efficiency and yield of the order noted above would be sufficient by themselves to justify the installation of process-control computers in plants of 200-300 tons per day capacity, which is not uncommon. With capacities of this magnitude--and some recently built plants in the U.S. have a capacity of 1000 tons per day--manpower savings are not the main factor in the decision to invest in a computer. In the firm studied, with a plant capacity of only some 80 tons per day, computerization was contingent on savings in manpower additional to efficiency and yield increases. The projected savings of 21 operator-shifts per week, resulting in a fivefold productivity increase, was cited in justification of the decision; the predicted savings were actually realized from the very start of the computer-controlled operation.

System Reliability and Process Safety

Apart from the first few months of operation, the overall system reliability has been extremely good. Several of the electronic instruments, such as transmitters and set-point station hardware, represented a relatively new line of instruments at the time of installation and had a high initial failure rate. Even though these instruments still do not perform entirely satisfactorily, very few actual failures are recorded and minor inaccuracies are catered for automatically.

The Bunker-Ramo RW-300 computer has proved to be as reliable as it was claimed to be. Since the plants went into unattended operation more than a year ago, the computer has not had a single breakdown. In order to deal with any such breakdowns should they occur, the firm has had one of its engineers trained by the computer vendor to provide immediate maintenance in case of need.

As far as process safety is concerned, an unattended plant compares very favorably with an equivalent plant under manual control. The potential for equipment damage, especially from undetected malfunction, has been reduced, as the computer is a more reliable monitor of equipment and process than an operator. For fire hazards, however, an unattended plant compares poorly with an attended one.

Details of Process

As noted above, an air separation plant performs two essentially distinct functions, viz.,

1) Liquefaction of Atmospheric Air by cooling and condensation at around -250°F and 1-5 atmospheres pressure.

2) Fractional Distillation to separate oxygen, nitrogen, and argon from the mixture to the desired degree of purity.

The products are stored in large insulated tanks at atmospheric pressure and delivered to the customer in small pressurized containers or in insulated mobile tank units (bulk deliveries). Apart from air, the only input to the process is electric power, so that firms have considerable freedom of choice in locating plants. In general they are situated near bulk consumers, and as a result air separation plants are to be found in all major industrial areas; but there are no major production centers. There are estimated to be well over 100 plants in the U.S. comparable in size or larger than the one studied here.

Selection of Firm and Technology Levels

The firm selected for this study provided the researchers with the unique opportunity of analyzing the manpower impact of a technological change resulting from fully closed-loop computer control and totally unattended operation of an air separation plant. The plant studied (actually two identical plants operated in parallel), which went into unattended operation in early 1966, was the first one to achieve this objective, and was known to be the only one in operation at the time of the study. Each plant is rated at 40 tons per day of liquid oxygen and liquid nitrogen, this in addition to a maximum recovery of crude argon.

The older plants are also still in full operation under manual control at the same location. In one of these plants, built in 1957 and rated at 25 tons of liquid product per day, an operator controls the process directly by manual adjustment of control valves. The other unit, which went into operation in 1961 and is rated at 40 tons of liquid product per day, is equipped with conventional automatic control instruments. One operator per shift runs both units together.

Even though the four plants studied are at three distinct levels of technology, only two levels were considered when analyzing the effects of technological change on manpower and skill requirements. These were manual and computerized control, where manual control refers to the mode of control in both older plants (i.e., operator control with and without the aid of automatic control instruments).

Operating Procedures

At the older technological level the operator's main activities consist in monitoring and controlling the values of process variables and in checking the performance of plant equipment. Though the operator is not conversant with the thermodynamic theory underlying the process, he has been trained to recognize the most important process relationships.

The values of the various process variables are displayed on measuring and recording instruments, some of which are located at various points in the plant, others on a central control panel. Whenever discrepancies are found between the measured and desired values of these variables, and whenever the latter values change, the operator adjusts the control valves and set-points of the appropriate controllers. Due to the interrelationships between the various variables and disturbances affecting their values, the settings for individual control valves and controllers are not self-evident. To reach a desired state several readjustments may be necessary.

At the newer technological level, the digital computer operates the entire process in the twin air separation plants. It is programmed to adjust the set-points of a large number of controllers according to values calculated by the control program. This is designed to maintain stable operation, optimize various equipment efficiencies, and ensure maximum yield of oxygen and/or nitrogen and/or argon as requested by the Distribution Manager.

Whenever the computer needs the value of a process variable for a control computation, it first checks for instrument failure and violation of process limits. If the scanning program, by which the value of each variable is updated once every eight seconds, has not indicated any such failure or violation, the computer uses the stored value in its control computation. Any malfunctioning of instruments and limit violations are typed out as error messages on a remote teletypewriter located in the nearby attended plants whose operator may then notify the maintenance department or one of the firm's engineers. However, this is a rare occurrence.

The values of the most important process variables are typed out on a logging teletypewriter once every hour or on demand. These variables can also be trend-printed at any frequency. The trend-log feature facilitates the analysis of instrument and process problems, and is mainly used by maintenance and supervisory personnel. Since the one computer operates the same process in twin plants, an indexing method is used whereby the monitoring and control activities of the computer are equally distributed between the two processes.

The only external operating control normally exercised is that of the Distribution Manager who enters his daily production requirements by means of punched tape at a remote tape-reader station in his office. The computer responds to these commands by appropriate modification of its operating policies to secure maximum compliance with marketing needs.

For a more detailed description of the process and control technologies, including the various computer programs, see Appendix E, Section 1.

Changes in Manpower and Skill Requirements

Data on both direct and indirect labor inputs to the two technologies were acquired in the single firm studied by the same methods used in previous studies. The results for the older technology were verified by qualitative comparison with data from another two firms employing similar technologies, but as noted above the newer technology was unique at the time of writing, and no comparison was possible.

Direct Labor

As shown in Table 6.16 and Figure 6.8, computer control of the air separation plants was found to have reduced the already low direct manhour requirements of the manually controlled plants essentially to zero. The reduction fell just short of 100% since an operator in the firm's nearby (older) plants was charged with responding to visual alarm signals and to simultaneous messages on remote teletypewriters. Receipt of an alarm message, however, did not imply the temporary substitution of manual for computer control. All the operator was required to do was to notify the repair and maintenance function or management.

The mean skill level of the very small direct labor input under the new technology was the same as under the older.

Indirect Labor

Indirect labor consists of two main components: supervision of operating crews and maintenance. There are distinct maintenance crews attending to mechanical equipment (i.e., compressors, expansion engines, etc.), and others, concerned with measuring instruments, automatic control equipment, etc.

Elimination of the need for a plant foreman was the main item responsible for the recorded decrease of 20% in total indirect labor manhours shown in Table 6.17. The 11.6% drop in mean skill level was also completely accounted for by the withdrawal of the plant foreman from the second highest skill level category.

There were no changes in either the manhour inputs or the skill levels of the maintenance personnel--the maintenance mechanic and his helper--or of the laboratory technician who makes a daily check of the stream analyzer calibrations. There was a change in the manhour input required from the instrument technician who attends to the pneumatic and electronic control instrumentation, but this was so small that it is not reflected in the tables and figures.

Overall Changes in Manhour and Skill Requirements

The net effect of the change to computerized technology in the air separation plant studies has been an impressive reduction of over 80% in total manhour requirements (see Figure 6.9); where the labor input for the 80 tons of product manufactured per day was nearly 31 manhours in the manually controlled plants, it is just short of 5 hours in the unattended plants. Nearly all of the remaining manhours are contributed by indirect labor--the maintenance crews and the technicians. These manpower savings add up to a productivity increase of 550%, all of it due to the technological advance in control equipment.

TABLE 6.16: DIRECT LABOR SKILL DISTRIBUTIONS FOR NORMALLY CONTROLLED (TL1) AND COMPUTER CONTROLLED (TL2) AIR SEPARATION PLANTS.

Organization: Air Products Firm

Process: Air Separation Product Unit: 10 Tons

Technology (Level 1): Manual Control

Technology (Level 2): Computer Control

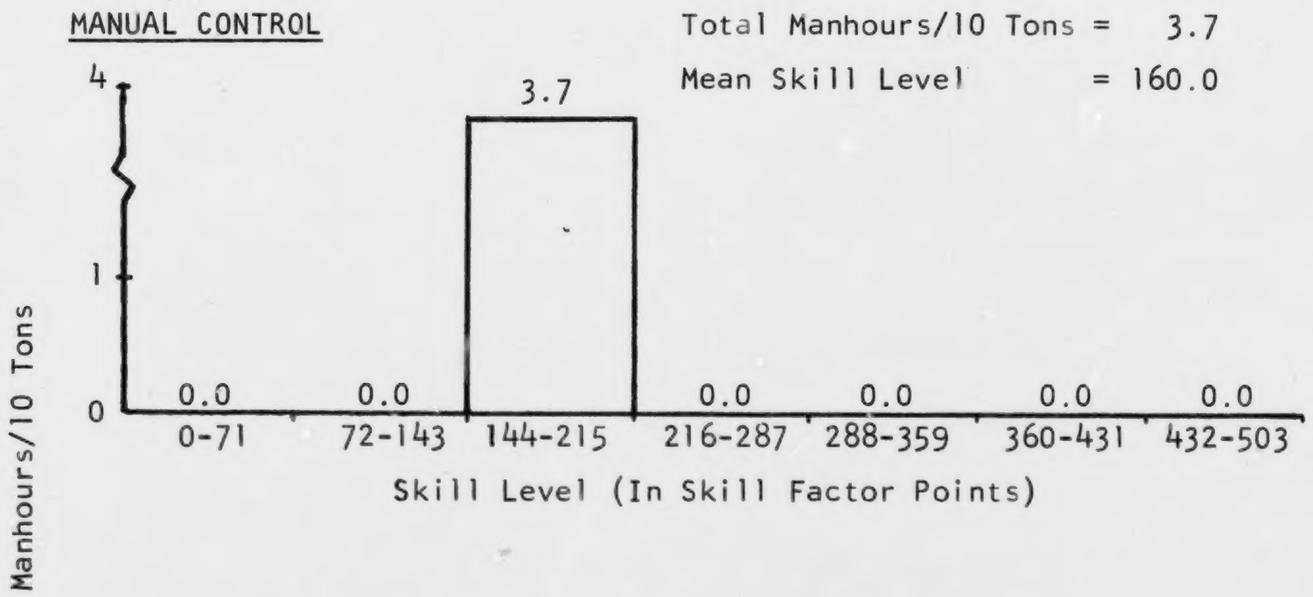
Source of Data: Direct Observation

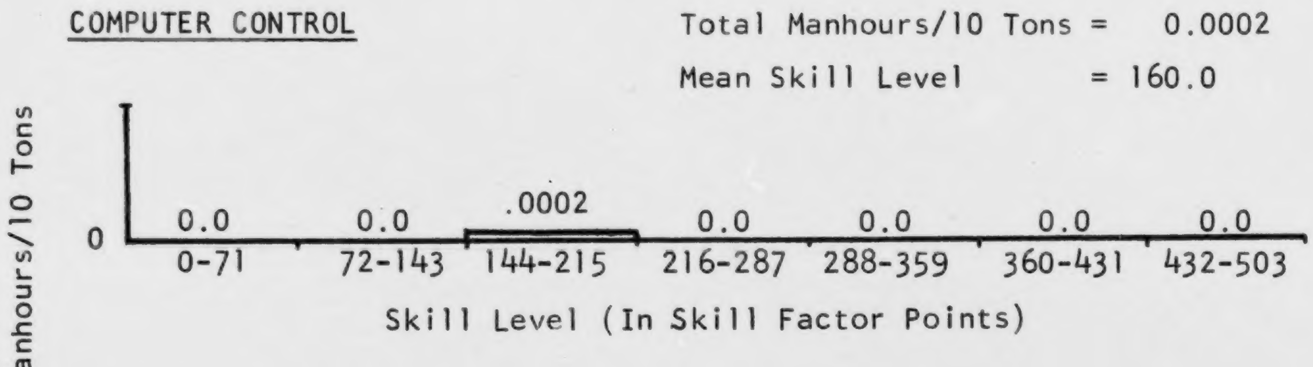
Period: Summer-Fall 1967

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10 Tons			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6	432-503									
5	360-431									
4	288-359									
Medium 3	216-287									
2	144-215	3.7	.0002	- 3.7	100	100	0	1	1	0
Low 1	72-143									
0	0- 71									
	Totals	3.7	.0	- 3.7	100	100	0	1	1	0
	Net Manhour Change -99.99%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	160.0	
Technology (Level 2)	160.0	
Change	0.0	

FIG. 6.8: DIRECT LABOR SKILL PROFILES--AIR SEPARATION PLANTS





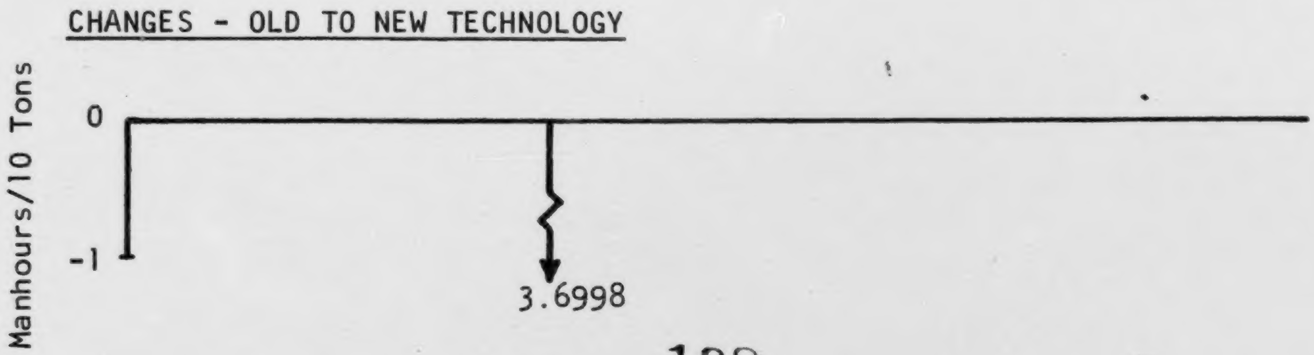


TABLE 6.17: INDIRECT LABOR SKILL DISTRIBUTIONS FOR MANUALLY CONTROLLED (TL1) AND COMPUTER CONTROLLED (TL2) AIR SEPARATION PLANTS.

Organization: Air Products Firm

Process: Air Separation Product Unit: 10 Tons

Technology (Level 1): Manual Control

Technology (Level 2): Computer Control

Source of Data: Direct Observation

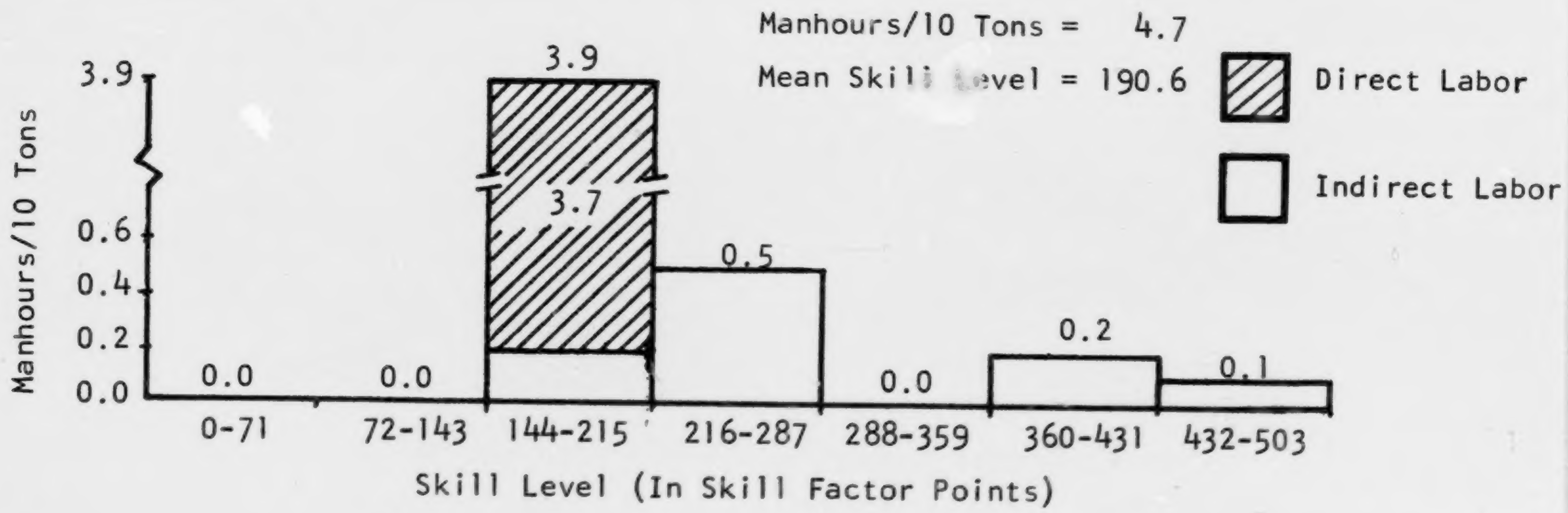
Period: Summer-Fall 1967

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10 Tons			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6	432-503	0.1	0.1	0.0	10.0	12.5	+ 2.5	2	2	0
5	360-431	0.2	0.0	- 0.2	20.0	0.0	-20.0	1	0	- 1
4	288-359	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Medium 3	216-287	0.5	0.5	0.0	50.0	62.5	+12.5	1	1	0
2	144-215	0.2	0.2	0.0	20.0	25.0	+ 5.0	1	1	0
Low 1	72-143	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0	0- 71	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	1.0	0.8	- 0.2	100.0	100.0	0.0	5	4	- 1
	Net Manhour Change -20%									

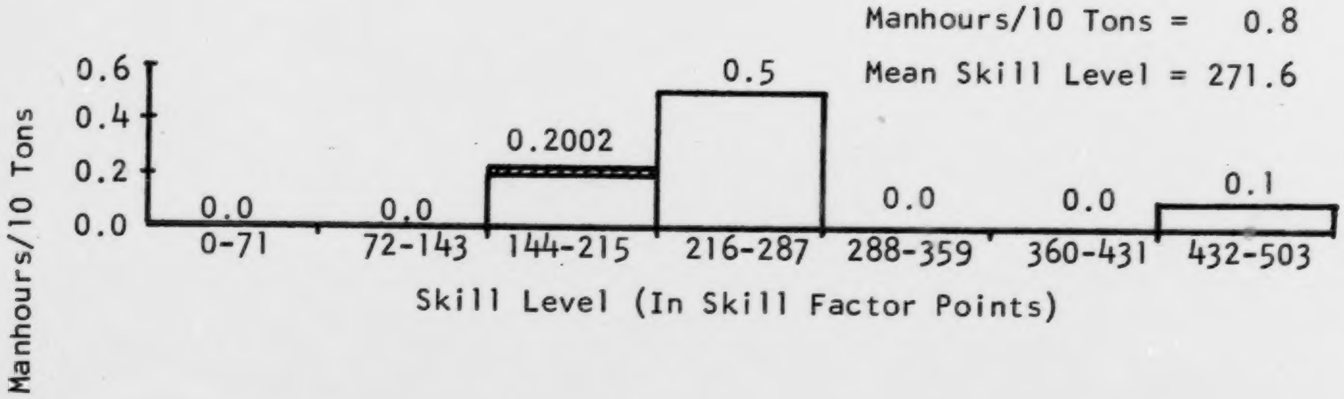
	Mean Skill Level	Standard Deviation
Technology (Level 1)	307.1	59.0
Technology (Level 1)	271.6	82.4
Change	- 35.5 (11.6%)	

FIGURE 6.9: COMPOSITE (DIRECT AND INDIRECT LABOR) SKILL PROFILES - AIR SEPARATION PLANTS

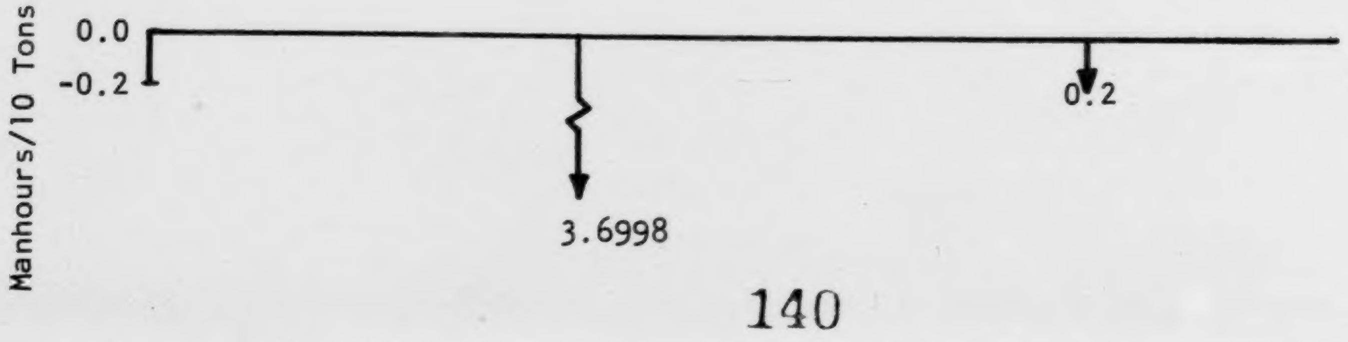
MANUAL CONTROL



COMPUTER CONTROL



CHANGES - OLD TO NEW TECHNOLOGY



The overall mean skill level of the labor force rose by some 43%, from 190.6 for the older to 271.6 for the newer technology, the latter skill level being of course that of the indirect labor input, as no direct labor remains.

Changes in Educational and On-the-Job Experience Requirements

Estimates of the length of education and on-the-job experience required of both indirect and direct labor under both technologies are given in Appendix E, Section 4. Neither of these requirements changed with the advent of the newer technology.

6.5 Conclusions on the Manpower and Skill Impact of Computer Process Control

Two of the three studies reported here concerned important processes in industries recognized to be leaders in the application of process-control computers, so that they may be regarded as fully representative of an advanced and well established technology. The third concerned a currently unique development in a smaller industrial grouping, but is considered a harbinger of future progress. In many respects the findings reported above offer important correctives to many current notions about both the extent of the use and the impact of process-control computers. Especially it is evident that in the major and technologically most adventurous industries at the present time, process computers are not applied to secure immediate and complete replacement of human operators on all plant control and regulative functions.

Oil Industry

In all three cases of catalytic crackers--the site where at the present time oil firms install their first and (sometimes) only process computers--only a small fraction of the variables regulated from the central control room come under full computer control. In general the computer is looked upon mainly as a means of performing more sophisticated regulation and optimization, hence securing greater yield and efficiency. It also provides a faster means of making system status information available to operators, and keeps complete regular records of system time history.

Accordingly, introduction of computers did not affect the size or skill of the operating crews to any marked extent; indirect labor requirements even increased slightly, owing to the addition of computer maintenance technicians. The basic pattern of skill distribution is reportedly about the same as it was when catalytic crackers came into widespread use. Like many other refinery processing plants, the crackers are dependent for routine stable operation mainly on numerous conventional (analog) automatic control loops.

The chief obstacle in the way of a more extensive deployment of the computers in catalytic cracking installations, and presumably elsewhere as well, lies in the software deficiencies--the lack of program routines capable of coping with the multiplicity and complexity of the conditions that can arise. As program development progresses, more and more variables can be expected to come under computer control, enabling the computers to operate in the closed loop mode for longer and longer periods. Even then reductions in direct labor requirements are likely to occur only very gradually and are liable to be counteracted in part by increases in maintenance and technical requirements. There is, however, no likelihood of a reversal in this progression, since the actual and future potential contribution of computers to improved quality and higher yield in the oil industry is beyond dispute.

Electricity Generation Industry

In the two steam electric power generation plants equipped with process computers, their immediate impact has been even smaller than in the refineries. Up to the present they have only been used in the closed-loop mode for continuous control in very few functions of the plants studied, which are among the most advanced in the country. Computer-mediated closed-loop operation does occur for relatively brief periods on those (infrequent) occasions when the plant is shut down for repairs and overhaul, and again when it is started up. Otherwise the computer acts as hardly more than a device for alerting operators to untoward plant conditions, a source of instant status information, and to execute rapid efficient plant performance calculations. The latter function contributes indirectly to optimizing yield and efficiency.

Under the circumstances no manpower changes would be expected and none have occurred, apart from a small extra provision for computer maintenance. There has been no change in skill requirements. In every essential feature the running of the plants having computers was found to be no different from that of the centralized plants. Because of the limited computer utilization and absence of tangible pay-offs to compensate for the heavy investment costs, computers are less firmly established here than in the oil and other process industries. Further the programming (software) problems are, according to the utilities engineers, among the most difficult to be found anywhere. For these reasons process computers have not been included in the design of some of the most recent plants. Further gains in productivity that might accrue from small reductions in operating personnel due to process computers are dwarfed by the large gains in productivity accruing from steadily increasing plant capacities permitted by advances in generation (rather than control) technology.

Air Separation Process

Whereas the oil refinery and power generating plant processes can be described as being still under computer-aided semi-automatic control, the air separation plant which was the subject of the last study in a process industry, is entirely computer controlled. The plant is at present the only one of its kind in the country, and is almost certainly also the only example in the world of an unattended complex industrial production process which is completely unattended--a process requiring zero human labor input. It is thus the only plant conforming exactly to the popular idea of full automation. The distribution manager simply "dials in" the amount and type of product needed to meet the demand and it is automatically delivered.

But generalization from the very considerable achievement represented by this case of computer regulation should be qualified by recognition of certain technical considerations which make full computerization a relatively easier undertaking in air separation plants than in refineries, generating plants and other process plants. Firstly, the raw material, being air, is available in unlimited quantities at uniform quality and with no transportation required. Secondly, there are only three main products (oxygen, nitrogen, argon) and little fluctuation in quality specifications. Thirdly, the process itself, while complex with many interacting variables, is subject to very few disturbances once equilibrium conditions have been attained. Startups and shutdowns are very infrequent.

The importance of these factors is underscored by the fact that a single relatively low skilled operator was enough to control the plant prior to computerization. There is no question that the two other processes studied are much more complex, and in general more typical of the control requirements encountered in the majority of process industries.

However, these advantages (for full automation) have so far only been fully exploited in one single organization, replacing effectively one single operator (per shift). Evidently the advent of full automation through application of process computers in manufacturing industry is much slower and more hesitant than many prophets forecast in 1945-50 when computers were first developed. But this example shows there is now a genuine precedent for that total abolition of direct labor requirements.

General Outlook for Further Impact of Process Computers

Despite the single instance of the zero-labor air separation plant, our overall quantitative conclusion is that process computer applications have little or no impact on manpower and skill requirements of process industry. Thus the rapid spread of their application entails no specific labor policy. However, extrapolation from the air separation case suggests that there may in the relatively distant future (perhaps the middle 1970's) be a rapid spread of fully automatic control systems in electricity, oil, chemicals, paper and other process industries. The evolving technological situation should be monitored to provide early warning of redundancies among process workers if and when this development occurs.

CHAPTER 7: IMPACT OF COMPUTER-BASED CENTRALIZATION ON RANDOM DEMAND REAL-TIME SERVICES: AIRLINE RESERVATION SYSTEMS (DIRECT LABOR ONLY)

7.1 Introduction

Random demand real-time service systems are those where requests for service arrive at random time intervals and/or from random sources, and must be met within relatively short fixed periods so that batching is not possible. Supermarket checkout systems and dial telephones are familiar examples. In many cases in these systems the points at which service is given are distributed over a large geographical area to suit the location of customers. Before the advent of automation, the services were mostly provided by human labor. Such systems are common throughout the economy; they are particularly interesting in the context of this research since computers and modern communications equipment are making substantial inroads into the manpower and skills required; in fact, some of these services, such as 24 hour automatic vending machines, came as a direct result of advances in mechanization and communication techniques. However, at present they depend solely on digital computers.

The telephone system is probably the most familiar as well as the most characteristic RDRT system. Other instances are electricity distribution, gas, water and utilities generally, airline, coach and theater reservation systems, stock brokerage houses and account services in banks supplying information on the state of customer balances; related, but not strictly real time, are mail order businesses, retail and distributive trades and services, etc.

It is convenient to distinguish RDRT systems which supply goods and energy--stores, electric utilities, gas stations, etc.--from those which accept, supply, or transmit information and data: bank tellers, credit bureaus, reservation systems, etc.

The process of meeting a demand for service involves:

> The recognition, recording and short term storage of customers' requirements.
>
> A search for goods or information to meet them (which may or may not include calculations and data transformations through the available capacity).
>
> Inventory or records of inventory to determine if and how the customers' demands can be met.

> The transport or delivery of the product or required information back to the customer, with a request for payment where applicable.

In the old fashioned manual telephone exchange, for example, the operator used to note the caller's request for a specific number, hold it in memory, or "store" it, by writing it down on a scratch pad, while she searched the plug board; and "deliver" the required connection by making the requisite plug insertion (or deny it, by informing the caller of its temporary or permanent unavailability). All of these functions proved readily amenable to performance by automatic switching circuits having random access facilities and linked to appropriate peripheral equipment, e.g. uniselectors and relays. Thus the telephone system is almost fully automated.

In many RDRT services, however, human operators continue to be employed essentially as encoders and decoders at the customer/system interface, especially where the information incorporating the customer's requirement is extensive and complex, and has to be translated and ordered into a pre-determined sequence to make it acceptable to a machine system.

General background and field observation led us to believe that computerization or full mechanization of RDRT systems can be identified as a distinct technological advance which took place some time ago in such cases as telephone, gas and water systems; is currently taking place in airline reservations systems, electricity generation, banking, etc.; and is now foreseen in retailing, gasoline distribution to the public, hotel and motel services, etc.

The feasibility of studying the manpower and skill changes attendant on computerization was explored in three kinds of RDRT service systems. The first of these, the bulk gasoline distribution system of an oil company, was rejected because the equipment through which the computer communicates with drivers taking on loads of gasoline at the loading ramps, was found to have been installed too recently and was not as yet dependable; it seemed likely that it would be some time before the new manning requirements had settled down enough to provide reliable data. This was decided after visits to several loading sites and after exploratory discussions with management.* A second case--the electricity dispatch centers of two large electricity utility companies--was examined in outline and may yet provide a useful comparison, but the preconditions for a controlled comparison could not be established.

Our major attention was finally devoted to examination of a third kind of RDRT service, airline passenger seat reservation. This was accomplished in two airlines. Descriptions of their systems and comparisons of the manpower and skill demands of the older and newer technologies used are given in the following sections.

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*The preliminary data and process descriptions are on file with the authors.

7.2 Process Description

Evolution of Technology

A modern airline reservation system consists of a network of local facilities--reservation offices, airport offices and ticket offices--and of a central control facility, all interlinked by communication channels. For the system to operate efficiently, the information at each point must be processed rapidly and accurately, and must be made readily and quickly available to all other points. Hence the most important elements of a reservation system are the processing methods, information storage facilities, and communication capabilities. Though these systems nowadays handle a wide variety of information pertaining to passenger reservations, the following categories of information constitute the indispensable minimum for the completion of a reservation:

(1) the availability of seats on a particular flight

(2) a record of information regarding the passenger and his itinerary.

The main elements of the communication network are shown in Figure 7.1 and can be seen to revolve around the Central Control point. Communication is most frequent between Central Control and the Reservation Offices, and involves both types of information (1) and (2) above. The Reservation Office-Ticket Office and the Reservation Office-Airport Office channels are used much less frequently. The dotted lines between Reservation Offices in the figure represent links which have now been eliminated. Not shown are links between Reservation Offices and ground facilities which provide transportation and hotel reservation service to the customers.

The original procedure for making a reservation was aptly called the "Request and Reply" system. In this system, the Reservation Office had to teletype Central Control every time a customer requested a seat, to find out if space was available. After receiving the teletyped reply, the Reservation Agent then telephoned the customer to confirm the reservation or ask for another choice of flights. The need to handle two teletyped messages and two telephone contacts (even more if the first request was not available) made the time for completing a booking very lengthy. The 60-word-a-minute teletype, which was in universal use by 1938, provided a much more reliable means of communication than its predecessor, the radio-telegraph.

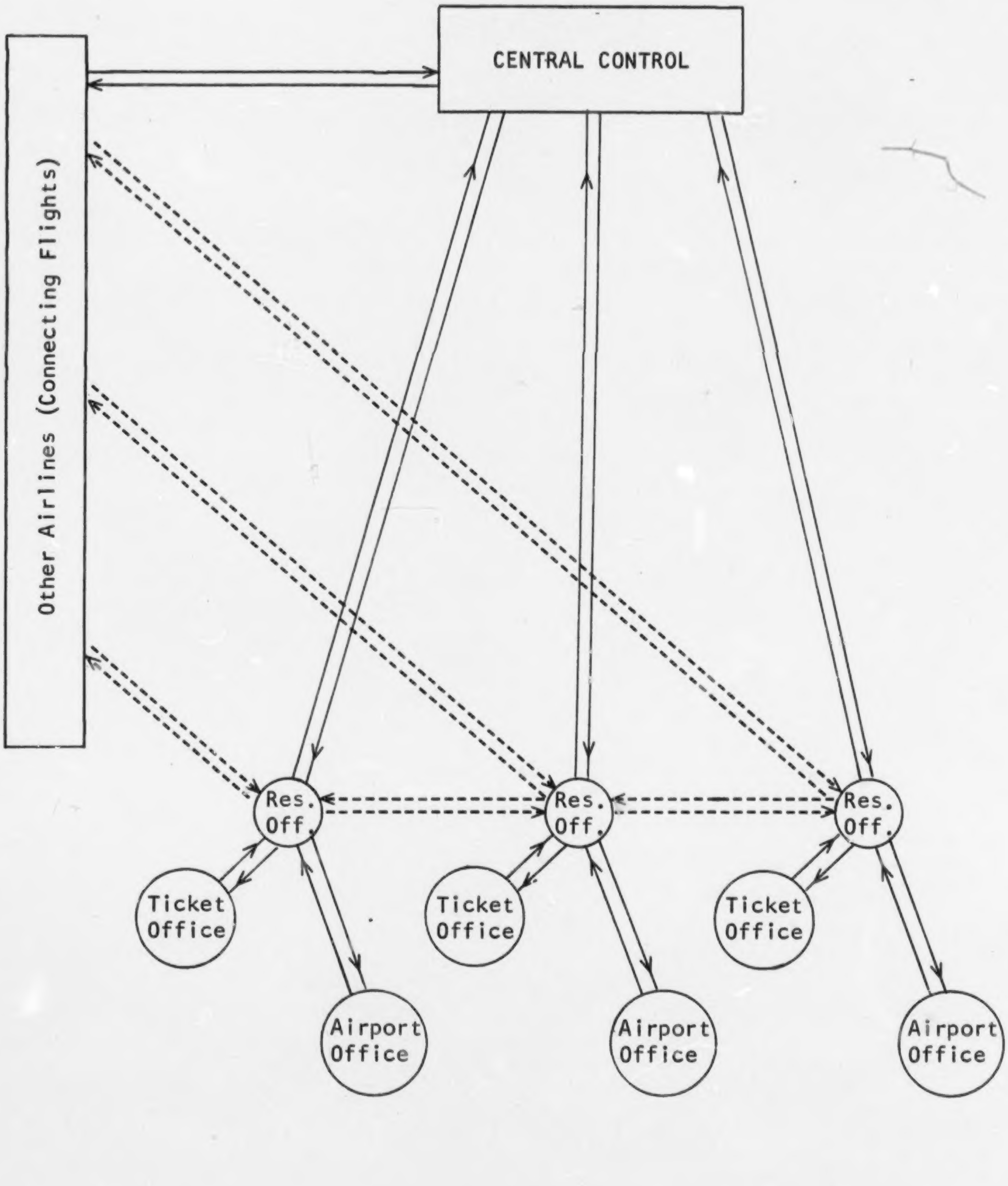
The introduction in 1939 of the "Sell and Report" procedure (described in detail in Appendix F) represented a substantial improvement and was soon adopted by almost every airline. It allowed the agent to freely book seats up to the time when a "Stop Sale" message was received in the Reservation Office, after which he had to revert to the Request and Reply procedure. The necessity for confirming provisional bookings to customers was thus largely eliminated. Moreover, a single message reporting the sale to Central Control replaced the to and fro, inquiry and reply, messages between Agent and Central Control where track was kept of the number of seats available.

The Stop Sale message went out to all Reservation Offices whenever all but a predetermined number of seats, referred to as a buffer or "cushion", had been sold. This cushion was an insurance against overbooking which could occur, should the sale reports in the pipeline exceed the number of seats still open. The size of the cushion depended on the communication time between Central Control and the Reservation Offices. Larger systems required more time, which in turn necessitated a larger cushion to take care of reports of sales, which might be enroute from the Reservation Office to the control point during the period that the Stop Sale message was enroute from the control point to the Reservation Office. When the Stop Sale message for a particular flight was received at the Reservation Office, it was displayed on a large availability display board which had dates for the next month across the top and flight numbers down the side. Different types of indicators were positioned in line with the flight and data to show whether the flight was open, on request, or closed. By looking at the board, the Reservation agent could promptly determine whether to immediately confirm a sale, request space from Central Control, or ask for another choice of flights or dates.

By the middle 1940's airlines were operating many more flights and Reservation Offices had become much larger. These developments created considerable problems in two areas. The first was congestion in the Reservation Office. Agents who were seated far from the display board had difficulty seeing it and identifying the indicator corresponding to the flight and data in question. Even utilizing duplicate boards did not help because the information on these boards often diverged from those on the master board. The second problem was communication delays inherent in a large complex network. The size of the stop sale cushions kept having to be increased, resulting in more frequent use of the slow Request and Reply procedure.

These problems of processing flight status information were overcome by the installation in one of the large airlines of a semi-automatic system. Individual reservation offices were equipped with Agent Sets having buttons for flight number, date, origin, and destination; each set was linked to a master control board consisting of a jack for every flight, date and leg. The presence or absence of a plug inserted in the proper jack indicated the status of the flight desired by causing a small light on the Agent Set to light up or remain off. The plugs were inserted by a Control Agent who received the reservation cards as sales were made and recorded them on a control chart until the cushion was reached.

FIGURE 7.1: NETWORK OF OPERATIONAL ELEMENTS IN AIRLINE PASSENGER RESERVATION SYSTEM


CENTRAL CONTROL
Other Airlines (Connecting Flights)
Res. Off.
Res. Off.
Res. Off.
Ticket Office
Ticket Office
Ticket Office
Airport Office
Airport Office
Airport Office

The semi-automatic system for which data has been collected in this study was very similar to the one described. It was introduced in 1956, and utilized central control units to service all Reservation Offices. For a more detailed description see Appendix F. Slight variants of this system were used by other airlines. In some cases the Agent Set was linked to a wired-program computer with a magnetic drum unit, which stored the number of seats available. The Reservation Agent reported a sale by moving a toggle switch on the set, causing the computer to update the inventory and activate the indicator lights when the cushion was reached. Another variation was the use of smaller local wired-program computers covering geographical sub-areas and linked to one central unit. By having the units service the Agent Sets in a smaller area, the distance over which the information had to be transmitted was reduced, and hence the speed increased.

As passenger volume continued to increase, the manual methods of handling, processing, and filing reservation cards could no longer cope adequately with the flood of reservation information. In the early 1960's computerized systems which allowed rapid recording, transmission, and access to all reservation information were put into use. These are described in detail in Appendix F.

In summary, the transition from the manual reservation systems to the semi-automatic technology was initiated by the need for more efficient handling of seat availability information, while the change to the computerized technology was compelled by the need for more effective processing of passenger reservation requests and data. In the further technological advances now contemplated or nearing implementation the electronic computer will play an increasingly important part. Four areas of development have been repeatedly mentioned in the course of the studies:

> Presentation of Information: In some of the newer systems, cathode-ray tube displays will supplement Input/Output typewriters. This will allow passenger reservation records and other information of transitory importance to the reservation personnel, to be visually presented faster and without noise.
>
> Ticketing: Computerized ticketing is certain to replace the present manual method of rate calculations in the near future. Complexity of rate structures has so far been the main obstacle.
>
> Communication: Several international airlines are experimenting with the use of space-satellite circuits to speed up communication with their overseas reservation offices, which at present chiefly rely on teletype.
>
> Interline Information Facilities: To facilitate reservation information interchanges between airline companies, the industry is now considering a central computer complex to which the member firms would have free access. Commercial considerations however make this development a rather distant prospect.

Choice of Case Material and Definition of Technology Levels

In selecting case material, it proved difficult to secure close comparability. From the total of some ten domestic and two overseas U.S. based airlines, which operate more or less advanced reservation systems, we initially selected two closely comparable domestic carriers for detailed comparison. Unfortunately, one of our two well-matched firms ultimately was unable to participate in the study for organizational reasons. We were forced by lack of better-matched case material to upgrade the international airline study to a more quantitative level and use it in a paired comparison with one of the domestic airlines selected. This resulted in a reasonable but not ideal research design.

Due to exigencies explained above, it was not possible to adhere to the research design including at least one replication which we have used in other studies, and the following incomplete design had to be adopted:

Case	Airline	Older Technology	Newer Technology
N	Domestic	Manual	Computerized
P	International	Semi-Automatic	Computerized

The drawbacks of this design are partly outweighed by the opportunity it afforded for the exploration of the manpower effects of all the three basic technologies that have been used in airline reservation systems. Since the entity processed and produced by any reservation system is information, the nature of the mechanisms by which information is processed, stored and transmitted would seem to be the most appropriate criterion for making distinctions between technologies, as it takes into account advances in equipment design while ignoring organizational peculiarities.

Accordingly the manual reservation system formerly operated in Firm N (N1), and now superseded in this as in all other national airlines in the U.S., depended primarily on human brains for information processing; on manually prepared lists, cards, records and files for information storage; and on communication devices compatible in their transmission rates with the limited intake capacity of the human receiver for transmission of information. This applied to both main types of information flowing through the system, seat availability information and passenger records. The flow was further slowed down by the need for numerous checks and controls to reduce the system's proneness to errors.

The main advance of semi-automatic reservation systems of the kind recently abandoned by Firm P (but still in widespread use) lay in the increased speed in handling seat availability information.

Only when semi-automatic systems (P1) took over, did the Sell and Report procedure become really effective. High speed transmission lines enabled the airline's central control facility to suspend the free sale of seats by every single agent at a monent's notice; as the safety margin or "cushion" of seats kept open could now be substantially curtailed, the frequency of occasions when the slower Request and Reply procedure had to be reverted to was greatly reduced. Thus, although semi-automatic operation affected only seat availability information, while passenger records continued to be processed and stored manually, the effect of the new technology was to accelerate the information flow and at the same time reduce the error rate.

The computerized reservation system technology in both Firms N and P, though fully run in, is nevertheless still developing, with new computer applications being tested and implemented. In Firm N, whose system (N2) is well ahead of Firm P's (P2) in versatility and sophistication, computerization has done away with both the local and central reservation control functions: an agent in any Reservation Office is at the push of a button informed by the computer not only whether or not seats are still available on any of the airline's flights, he is also told how many seats are still open for booking. Firm P's system is lacking in this second feature, and updating of seat inventories is still done by Reservations Control.

Local passenger record processing and storage have completely disappeared in both firms. All passenger information input by Reservation Agents on typewriters is immediately transferred to the drum and disc files of the central computer installation via high speed transmission lines. A time sharing facility insures that any Agent at any Reservation Office can, with little or no delay, get a print-out on any passenger whose record is on file. Firm N has additionally developed programs for pre-departure control and post-departure reconciliation of passenger handling.

Table 7.1 summarizes the main characteristics of the reservation systems at each of the three technology levels, further details being given in Section 1 and 2 of Appendix F.

7.3 Manpower and Skill Changes due to Computerization

Though the changes in passenger reservation systems technology have in all probability had some effect on all airline personnel, their most immediate impact was on personnel who help the passenger select his flight, and who supply the necessary information for getting him on and off the plane. This description fits virtually all employees at Reservation, Ticket and Airport Offices and at central facilities, and, insofar as they fall into the direct labor category, they have been included in the present studies. Excluded from consideration were, apart from managers at any level, all personnel concerned with scheduling, loading and operating aircraft, with baggage handling and baggage processing, and with rendering service in flight or contributing to such service (stewardesses, meal preparers, etc.).

Definition of Unit Product

A special problem arose in connection with the selection of a suitable "unit product". Number of calls which have to be dealt with seemed a good first choice; but though both firms keep a detailed record of calls, each of them includes different types of calls in its count; also the types of call included by one of the airlines have changed during the time period spanned by the study. Because of this, and also because passengers-boarded rather than calls are the final output of the system, number of passengers boarded was taken as the unit to which to relate the manhour inputs by the defined direct labor components of the reservation systems.

Accurate month-by-month figures on the number of passengers boarded for the total system are computed by every airline and are used by them for a variety of purposes. As the Central Control facilities in Firms N and P service the whole system, the manhour inputs by their personnel were divided by this total number of passengers boarded by the airline. Conversely, the per unit manhours of personnel at local offices were determined by reference to the number of passengers boarded at the airport serviced by each of these offices only. A small error is inherent in these local figures, since they include a small proportion of passengers who made their reservation in other cities; this is offset by the fact that the reservation offices under investigation similarly book passengers boarding at distant airports.

Changes in Manhour and Skill Requirements

The per unit manhours by skill level, technology and firm are summarized in Tables 7.2 and 7.3, and Figures 7.2 and 7.3. (See Appendix F for further details.)

Though the main subjects of study are the manpower and skill changes associated with the displacement of one technology by another, there are sizeable differences between the airlines in a number of other respects liable to attract disproportionate attention when Tables 7.2 and 7.3, and Figures 7.3 and 7.3 are compared. It may therefore be as well to dispose of them immediately.

For example, it appears that Airline N uses 36.2% less manhours per passenger at the older, and 46.5% less at the newer technology levels than Airline P. However, this is largely a reflection of Airline P having to provide more services to its substantially smaller number of passengers boarding for overseas destinations than does the domestic carrier N. Also it might seem that Airline N's reservation system personnel are significantly more skilled, as indicated by the higher mean skill level values at the older

TABLE 7.1: MAIN CHARACTERISTICS OF MANUAL, SEMI-AUTOMATIC AND COMPUTERIZED PASSENGER RESERVATION SYSTEMS

	Type of Information	Processing Methods		Information Storage		Communication Capabilities	
		Local Offices	Central Control	Local Offices	Central Control	Transmission Facilities and Speeds	Information Storage Access Time
Manual	Seat availability	Manually update board	Manually update listing	Board display	Manual listing	Teletype (60 words/min) Telephone (80-100 words/min)	Seconds
	Passenger record	Manually update file	None	Card file	None	Teletype (60 words/min) Telephone (80-100 words/min)	Minutes, hours
Semi-Automatic	Seat availability	Input/output device, Prenotched plate	Manually update listing	None	Manual listing, Wired circuit board	High speed transmission lines (2700 words/min)	Immediate
	Passenger record	Manually update file	None	Card file	None	Teletype (75-100 words/min)	Minutes, hours
Computerized	Seat availability	Input/output device, Prenotched plate	Computer	None	Drum	High speed transmission lines (2700 words/min)	Immediate
	Passenger record	Input/output typewriter	Computer	None	Drum, disc	High speed transmission lines (2700 words/min)	Immediate

TABLE 7.2: SKILL DISTRIBUTIONS FOR MANUAL AND COMPUTERIZED RESERVATION SYSTEMS (AIRLINE N)

Organization: Airline N

Process: Passenger Service System Product Unit: 100 Pgrs. Boarded

Technology (Level 1): Manual Processing

Technology (Level 2): Computer Processing

Source of Data: Direct Observation and Firm's Records

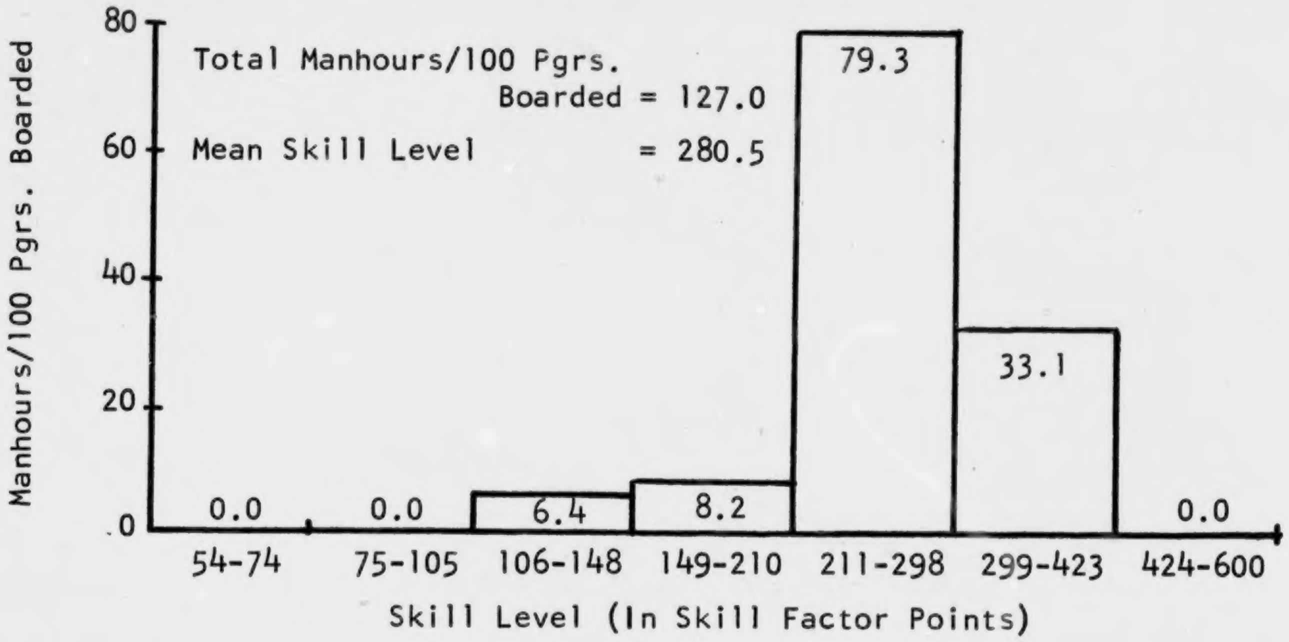
Period: 1960-1961 (TL1) and 1965-1966 (TL2) [Data Acquired - Winter, Spring 1967]

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 100 Passengers Boarded			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6	424-600	0.0	2.4	+ 2.4	0.0	3.1	+ 3.1	0	9	+9
5	299-423	33.1	37.3	+ 4.2	26.0	47.7	+21.7	4	4	0
Med. 4	211-298	79.3	35.8	-43.5	62.5	45.8	-16.7	8	9	+1
3	149-210	8.2	2.1	- 6.1	6.5	2.6	- 3.9	5	5	0
Low 2	106-148	6.4	0.6	- 5.8	5.0	0.8	- 4.2	2	1	-1
1	75-105	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0	52- 74	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	127.0	78.2	-48.8	100.0	100.0	0.0	19	28	+9
	Net Manhour Change -38.4%									

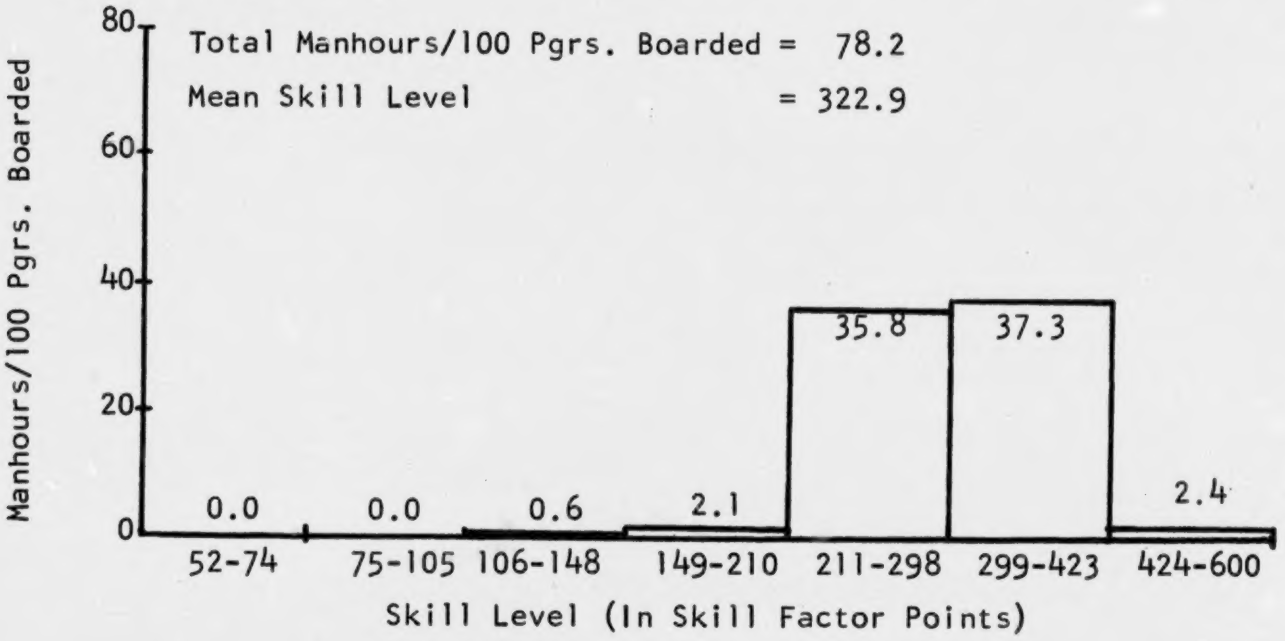
	Mean Skill Level	Standard Deviation
Technology (Level 1)	280.5	61.7
Technology (Level 2)	322.9	64.9
Change	+ 42.4 = +18.5%	

FIGURE 7.2: SKILL PROFILES FOR MANUAL AND COMPUTERIZED RESERVATION SYSTEMS (AIRLINE N)

MANUAL PROCESSING



COMPUTER PROCESSING



CHANGES - OLD TO NEW TECHNOLOGY

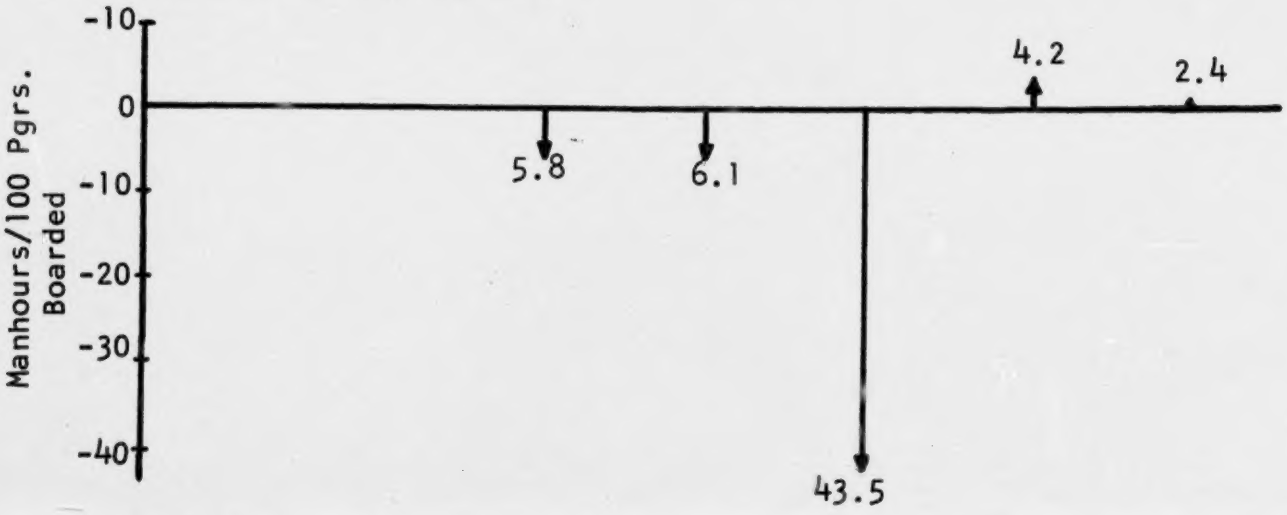


TABLE 7.3: SKILL DISTRIBUTIONS FOR SEMI-AUTOMATIC AND COMPUTERIZED RESERVATION SYSTEMS (AIRLINE P)

Organization: Airline P

Process: Passenger Service System Product Unit: 100 Pgrs. Boarded

Technology (Level 1): Semi-Automatic System

Technology (Level 2): Computer Processing

Source of Data: Direct Observation and Firm's Records

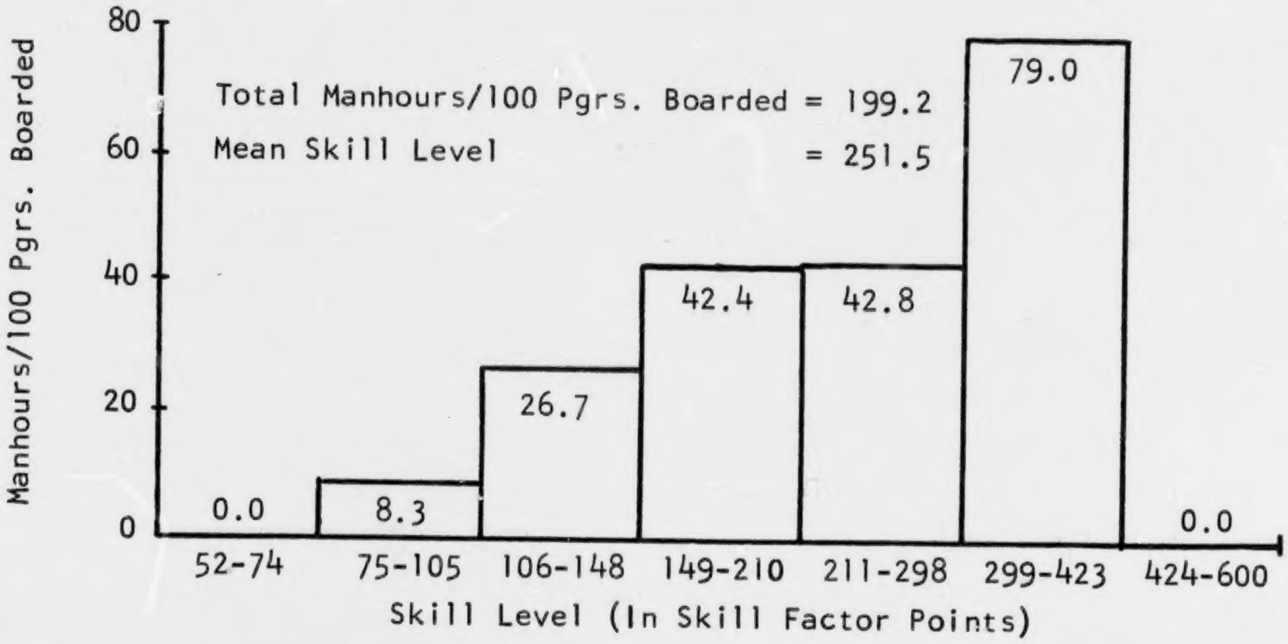
Period: 1961 (TL1) and 1966 (TL2) [Data Acquired - Winter, Spring 1967]

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 100 Passengers Boarded			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6	424-600	0.0	0.3	+ 0.3	0.0	0.2	+ 0.2	0	3	+ 3
5	299-423	79.0	66.2	-12.8	39.6	45.4	+ 5.8	9	11	+ 2
Med. 4	211-298	42.8	45.8	+ 3.0	21.5	31.3	+ 9.8	6	13	+ 7
3	149-210	42.4	11.6	-30.8	21.3	7.9	-13.4	7	8	+ 1
Low 2	106-148	26.7	10.1	-16.6	13.4	6.9	- 6.5	5	5	0
1	75-105	8.3	12.2	+ 3.9	4.2	8.3	+ 4.1	3	6	+ 3
0	52- 74	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	Totals	199.2	146.2	-53.0	100.0	100.0	0.0	30	46	+16
	Net Manhour Change -26.6%									

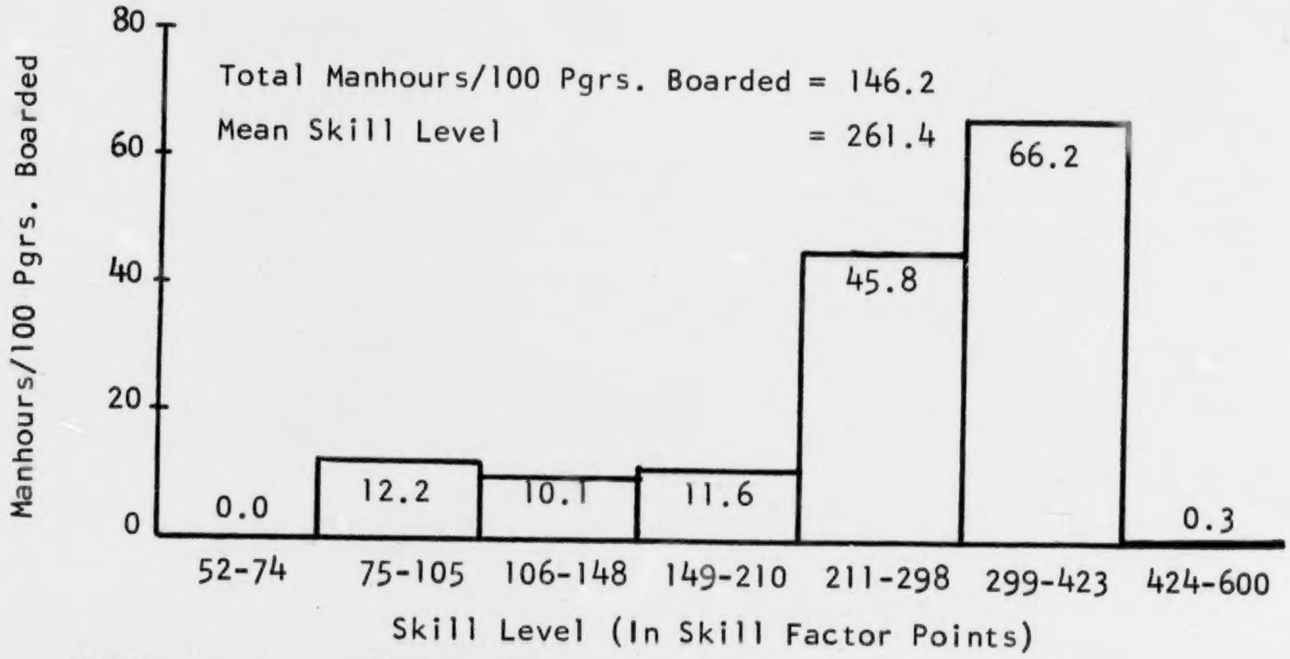
	Mean Skill Level	Standard Deviation
Technology (Level 1)	251.5	90.8
Technology (Level 2)	261.4	86.7
Change	+ 9.9 = +5.0%	

FIGURE 7.3: SKILL PROFILES FOR SEMI-AUTOMATIC AND COMPUTERIZED RESERVATION SYSTEMS (AIRLINE P)

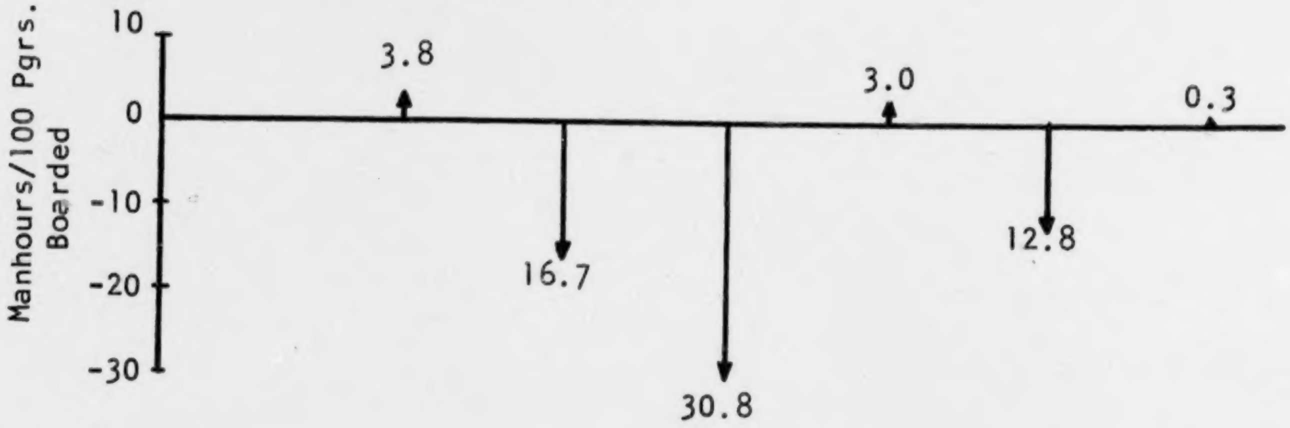
SEMI-AUTOMATIC PROCESSING



COMPUTER PROCESSING



CHANGES - OLD TO NEW TECHNOLOGY



and at the newer technology levels. But a more likely explanation of this observation lies in the fact that Airline N's job evaluation scheme was used to rate the skill levels of jobs in both firms, and Firm P's raters, being unfamiliar with the scheme, probably used different criteria in applying it. The technology-level comparisons would not be affected by this bias. This leaves only the inter-firm differences in the scatter of the profiles to be accounted for (cf. standard deviations); in this instance the effect is undoubtedly genuine and is organizational in nature. Where Airline N's structure is relatively undifferentiated, with few job categories each of a wider content, Airline P prefers more job categories of a more narrowly specialized kind. Whether this is related to the international and domestic character respective of the two airlines, or to some other factor, it is impossible to say.

Of the differences clearly identifiable as due to technology, there are firstly the gross reductions in per unit manpower inputs in each firm resulting from computerization: manhours per passenger boarded decreased by 38.4% in Firm N and by 26.6% in Firm P. Considering that, in converting to computers from a manual system, Firm N jumped a larger technological gap than Firm P, the larger decrease in the former is not unexpected. This same factor may also account for the larger rise in the mean skill level at Firm N (18.5%) as against Firm P (5.0%). These rises were tested for statistical significance in each firm separately. As shown in Table 7.4 the increase in the mean skill level associated with the change from manual to computerized procedures (Firm N) is very highly significant, whereas the increase in Firm P, which changed to the computerized technology from the semi-automatic, though in the expected direction, cannot be decisively distinguished from a chance effect.

A statistical test was also carried out to determine whether the observable changes in the skill distributions brought about by technological change were significant. Using analysis of variance, the manhour inputs in the two firms were compared at three skill levels (lower, medium, higher) and at two levels of technology.*
A summary of this analysis is given in Table 7.5, and more detailed data will be found in Appendix F.

As expected, the observed differences in total per unit manhours between the firms turned out to be highly significant. The interaction between skill level and technology, indicative of the effect of technological change on the skill distribution, though it is in the right direction, did not reach a conventionally acceptable significance level; this is largely accounted for by the absence of pronounced changes in the skill distribution of Firm P.

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*The manual technology N1 and the semi-automatic technology P1 were considered as constituting the same technology for the purpose of this analysis.

However, referring back to the significance tests on the rises in mean skill level, it can be legitimately argued that a change from a manual to a computerized system, such as occurred in Firm N, has a palpable effect on skill requirements. With the lower skills virtually eliminated, and the medium skills very substantially reduced due to the elimination of local control sections, the proportional preponderance of the higher skills becomes the most striking feature of the post-computerization distribution. The increased proportional dominance of the higher, relative to the lower and medium, skill levels is also present, though not quite as markedly, in the Firm P distribution.

7.4 Job Types, Education and Experience

Changes in the Number of Job Types

Reference was made in the preceding section to differences between the two firms in the scatter of skill values, and these were ascribed to organizational peculiarities, with Firm N favoring a less differentiated task allocation. These peculiarities are in fact revealed by the number of job types at each technology level being about 50% greater in Airline P relative to Airline N.

However, the technological advance also increased the number of job types by about 50% in each firm. In Firm N most of this increase is accounted for by the addition of the electronic data processing center. In Firm P more job types seem to have been created at nearly every skill level and at all points of the reservation network.

Changes in Education and Training Requirements

Due to the lack of adequate personnel records, no data could be obtained to assess quantitatively the required level of education for the various jobs involved in reservation systems. From qualitative discussions with management, two years college experience at Firm P appeared to be a basic qualification for almost all job holders, with the possible exception of such low-skilled jobs as Mail Clerk. Some college education was probably mandatory for all EDP personnel employed in the computerized systems.

Exact training and/or on-the-job experience data were also unavailable. There appears to be a little more variance in these requirements than there is for general education. The training period for most agents' jobs does not apparently exceed three months.

TABLE 7.4: STATISTICAL TEST OF CHANGES IN SKILL LEVEL REQUIREMENTS ASSOCIATED WITH REPLACEMENT OF MANUAL (N) AND SEMI-AUTOMATIC (P) BY COMPUTERIZED TECHNOLOGIES[*]

Firm	Change in Technology	Rise in Mean Skill Level	t - Value	D.F.	Significance Level
N	Manual to Computerized	42.4	4.63	204	P < .001
P	Semi-Automatic to Computerized	9.9	1.03	344	Not Significant

TABLE 7.5: STATISTICAL SIGNIFICANCE TEST OF CHANGES IN SKILL LEVEL REQUIREMENTS ASSOCIATED WITH CHANGES IN TECHNOLOGY[*]

Source of Variance	Degrees of Freedom	Variance Ratio	Significance Level
Between Skill Levels	2	35.82	P < .01
Between Technologies	1	10.97	P < .05
Between Firms	1	20.81	P < .025
SL x T	2	4.63	Not Significant
SL x F	2	2.39	
T x F	1	0.007	

---

[*] Detailed data in Appendix F.

Job Demands and Skills

The Reservation Sales Agent's jobs which exists at all three local offices and comprises a large number of manhours has been markedly affected by the changes in technology. At all technological levels, the Sales Agent must be prepared to provide any of a large variety of data within a short period of time--that is, while a customer is waiting on the telephone. This involves familiarity with many different standard references (Rate Schedules, Tariff Regulations, Flight Schedules, Immigration Guides, etc.) and with various other types of information (Passenger Lists, Seat Availability, Ticketing, etc.). The particular technology in use dictates the method of obtaining and supplying information. In a manual system, the Reservation Sales Agent had to be able to read the seat availability display board accurately to obtain flight status data, and had to know how to fill out and route the reservation card. In the semi-automatic technology the former requirement was replaced by the need to manipulate the "Teleregister" Agent Set. Since operation of this set was simple, the additional training time was insignificant. Input/output devices utilized in the computerized technology are more complicated and companies provide a training course which culminates in a test of speed and accuracy; to attain minimum proficiency, Reservation Sales Agents require approximately 2-3 weeks more training or experience than for the manual and semi-automatic systems which themselves require about 2-3 weeks.

Other jobs which require more than nominal training are the Reservation Control jobs (manual, semi-automatic), the Ticket Lift Agent (computerized), some of the jobs at the EDP (computerized), and the Rate Quotation function.

The Control activities require the assembly of reservation data and its subsequent dispatching to the proper location at the appropriate time, and minimum proficiency can probably not be attained in less than two months.

The Airport Ticket Lift Agent under the computerized technology, needs to be able to operate the Agent Set to obtain pre-flight information, dispatch post-flight reports, and process departure documents; for someone with no experience in related jobs, about 5 weeks is required for minimally proficient performance.

EDP analysts and programmers may require several months of training to learn the characteristics of the reservation system. (Note that the EDP function comprises only about 1% of total manhours per 100 passengers required for the computerized technology.)

The Rate Quotation function requires about 4 weeks to become minimally proficient at interpreting the complicated rate structures in order to determine the fares for a multitude of possible itineraries.

The time periods suggested as necessary to attain minimum proficiency are the researcher's estimates based on knowledge of job activities, together with verbal discussion with the managers of the various offices visited.

7.5 Discussion of Skill Impact of Computerization in Airline Reservation Systems

Airline passenger reservation facilities combine elements of two interrelated information processing activities differing in timing. Providing prospective passengers with seat availability information places them in the category of a random demand real time system. Recording details regarding passengers and their itinerary, and passing on these details to departments charged with accommodating and transporting them, is essentially an off-line information processing function having certain similarities with e.g., check processing and account posting in banks.

There is little doubt that rapid and accurate response to customer reservation requests has been a major operational problem since mass air transportation became a reality. This explains most of the development towards simplification, then towards semi-automation, and finally to computerization. However, once computers were installed, it was inevitable that they would take over the processing and storage of passenger reservation records, which would soon have become a bottleneck.

Neither semi-automation nor computerization were explicitly aimed to provide manpower savings, and the productivity gains achieved resulted from the more advanced system's capacity to cope with larger volumes of passengers rather than from reductions in manning. Some reductions did occur especially at those points of the system where seat availability information was being assembled for dispatch to the terminal points (reservation agents) in direct contact with increasing demand. Assembly of this information had already become progressively more centralized; computers completed the development, programmers and other computer staff displacing clerical control staff in the process. The new staff has a much higher skill level average, but also so few manhours per unit product that they hardly figure in the distributions.

At the local reservation facilities changes occurred in layout, methods and procedures, and consequently also in the skill requirements which are higher for most personnel. These arose from the need to manipulate terminal equipment, to coordinate actions for retrieving information from the central computer installation while keeping the customer on the line, and to compute and monitor larger and more complex blocks of information.

Future developments are likely to include still further means of information interchange between the outlaying points and the central computer to facilitate reservation agents' tasks. There are however no indications that the time required to complete interchanges with customers can be significantly shortened, nor that human intervention between computers and customers can be eliminated. Increases in skill requirements also are unlikely. So far as can be seen, the total manhours, and thus the number of agents, will remain proportional to the passenger volume.

These conclusions however do not necessarily apply to any and every random demand real-time system. Direct customer access to computers in banks, for example, may ultimately eliminate personnel required for answering queries regarding states of customer balances. Similarly, the random demand real-time functions performed in supermarkets by the checkers may disappear, giving way to automatically monitored customer self-service.

CHAPTER 8: CONCLUSIONS ON THE MANPOWER AND SKILL IMPACT OF TECHNOLOGICAL CHANGE

The objectives of the research presented in this and the previous report (Ref. 1) were twofold, first to develop a methodology capable of precisely delineating the impact of technological change on manpower demand at micro-level; and second, to provide statistically sound evidence on the extent of changes in manpower and skill demands caused by automation, based on a cross-sectional sample of technological changes in manufacturing and service processes.

The first objective was accomplished in two stages and the resulting quantitative approach to manpower demand analysis, based on the "skill profile" concept, is set out in Chapter 3 above. In the first phase of the project a method was developed for measuring direct production labor and skill requirements. In the second phase, which is the subject of this report, the feasibility has been demonstrated of extending it to indirect labor and thereby covering the total process-related workforce.

The second objective was achieved through field studies comparing manpower requirements before and after major technological changes in 18 production and service processes, drawn from 6 selected process types. Detailed results have already been presented above,and specific conclusions on individual processes and technologies were discussed in the relevant chapters. It remains now to summarize and integrate our overall findings, draw general conclusions, and use them to project some of the likely manpower effects of future technological advances.

Technological advance generally has both quantitative and qualitative effects on manpower demand. Thus the total quantity of labor usually diminishes, an effect conventionally measured by the improvement in output per manhour--labor productivity. Secondly, the quality of labor required is generally different after the advance. In our study this change is measured by comparing the old and new skill profiles--the changing distribution of skill levels. We discuss these two aspects of the manpower impact of technological change separately in this and the following sections (8.1 and 8.2). In both cases direct and indirect labor are taken separately, partly because it is instructive to distinguish the two components within the overall manpower impact, and partly because we have much less complete data for the latter.

8.1 Technological Change and Labor Productivity (Quantitative Changes in Labor Input Per Unit Product)

Direct Labor

Considering first the direct labor data summarized in Table 8.1, we note that all except five of the eighteen processes studied showed decreases in manhours required per unit product, equivalent to increases in labor productivity. These reductions are attributable to technological change, and the data thus support the popular assumption that labor productivity tends to increase with technological change. This is expected because those initiating technological change often do so to secure cost reduction, and direct labor, being generally a major component of unit cost, is a leading candidate for elimination.

The five exceptions were all cases where the direct labor force was the same before as after the technological change. We encountered no instances of increased direct labor requirement.

Indirect Labor

The subsequent evaluation of indirect labor requirements caused an upward revision in the measured total post-change manhour requirements for seven of the eight cases in which we were able to determine them; this corresponds to a downward revision of the measured labor-productivity gains. The direction of this revision again was expected and confirms the perhaps somewhat less widely held view that, since indirect labor accounts for a greater fraction of the total labor force in more technologically advanced or more highly automated processes, its inclusion will somewhat dilute the manpower impact of technological change. In our cases most of the indirect labor requirement was identified with supervision and maintenance.

Total Labor Force

The computation of productivity changes for the total labor force, in those cases where the data was available, revealed a small but distinct net decrease due to technological change in as many as four cases. These were an electric power plant and three oil refinery units. Thus it seems that the implementation of technological change does not necessarily improve labor productivity--it actually caused a decline in no fewer than 50% of all processes for which full data were available.

However the extent of gains in the other 50% of cases far outweights these small losses, and the aggregate productivity gain

TABLE 8.1: SUMMARY OF MEASURED PRODUCTIVITY CHANGES

Technological Change	Sample Process	Industry	Product Unit	Direct Labor Output Per Manhour			Overall (Direct and Indirect) Output Per Manhour		
				Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change
Machine-aided manual to computerized	Demand deposit accounting	Banking	1000 items processed	33.0	62.5	+ 89.4%	28.7	56.5	+ 96.6%
				46.5	58.8	+ 26.5%			
Batch to continuous process	Annealing strip	Steel	10 tons	4.8	7.7	+ 61.6%	2.8	3.1	+ 10.8%
				4.0	6.3	+ 56.3%			
	Coating strip (galvanizing & tinplating)		10 tons	0.8	2.6	+ 233.3%			
			100 base boxes	9.3	34.5	+ 271.0%			
Conventional to numerically controlled machinery	Machining aircraft parts	Aerospace	1 part	0.26	0.37	+ 40.7%			
				0.26	0.50	+ 90.1%			
Decentralized to centralized control	Power generation	Electric utility	1 plant operating hr.*	0.10	0.19	+ 92.0%	0.04	0.07	+ 54.5%
				0.11	0.22	+ 93.7%			
Conventional analog to digital computer process control									
Monitoring & performance calculations	Power generation	Electric utility	1 plant operating hr.*	0.25	0.25	0.0%	0.10	0.09	- 8.6%
				0.22	0.22	0.0%			
Partially closed loop	Hydro-carbon cracking	Oil	1000 barrels	322.5	322.5	0.0%	268.1	260.4	- 2.9%
				285.7	285.7	0.0%	236.4	231.7	- 1.9%
				250.0	250.0	0.0%	162.3	151.3	- 5.5%
Fully closed-loop	Air liquefaction & separation	Chemical	10 tons	2.7	5000.0	+1850.8%	2.1	12.5	+486.9%
Semi-automatic to computerized random demand real time service	Airline passenger reservation systems	Air Transportation	100 passengers boarded	0.78	1.27	+ 62.0%			
				0.50	0.68	+ 36.0%			

*Electric power plant productivities are expressed in plant operating hours rather than kwhrs to discount increases in plant capacity changes which occurred simultaneously with changes in process control methods.

over all processes would undoubtedly be positive.[*] On examining collateral data obtained from management, it appears that some technological changes were initiated despite an anticipated (small) increase in labor cost per unit.[†] This was more than offset by improved yield and plant utilization, so that a net economic gain actually resulted.

To summarize, our data support the accepted view that technological change increases labor productivity. But allowance must be made for a significant minority of cases in which technological change produces no change in labor productivity or even a slight decrease. This result is expected when changes are made in already highly sophisticated processes with minimal pre-change labor requirement.

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[*] This cannot be computed without adopting a measure of product value.

[†] It might be argued that in these cases potential productivity increases were masked by inelasticity of the in-plant labor force, that is by management's inability to reduce the labor force to match the new technological situation. This might be due, for instance, to trade union contract limitations. However, collateral observations indicated in at least one case that the workloads of operating crews were increased rather than reduced by the technological change.

8.2 Productivity Changes by Process Types

8.2.1 Automatic manipulation of materials and data

We turn now to labor demand comparisons between different process types and different patterns of technological change.

The magnitude of labor productivity gains accruing from the technological changes studies were found to be greatest for those older technologies--mechanized check processing, batch annealing and galvanizing, conventional machine-tool operation, and the manually operated airline reservation system--which entailed substantial amounts of direct human manipulation of materials and data (Table 8.1). In all of these cases the observed decrease in per unit labor requirement was achieved by one of the following means:

(a) Elimination of the need for detailed manipulation of materials--e.g., by continuous processing.

(b) Transfer of detailed control over manipulations from the human worker to pre-programmed electrical or hydraulic control devices--e.g., by numerical control of machine tools.

(c) Replacement of human brainwork in detailed data-transmission, storage and processing operations by digital computers and other electromechanical devices--as in computerized check processing and airline reservation systems.

We may perhaps conclude that large decreases in per unit manpower requirement occur only where the technological change includes mechanization of human tasks and where direct human manipulation of materials or data was prevalent in the pre-change process. Even here the productivity increases recorded were far from startling.

8.2.2 Human interface between customer and system

It is particularly noteworthy that the only two processes where the post-change functions of the labor force still included direct manipulation of materials and data were the two service sector processes, check processing and airline reservations. In both of these, collateral observations revealed that the prime reasons for retaining the human element was to provide an interface between the (unchanged) human customer and the new mechanical information-processing system; the jobs in question were bank tellers and airline telephone sales agents. If it had not been for these two necessarily human labor inputs, both processes would have shown markedly greater productivity gains due to computerization.

Thus the inclusion in the sample of two processes directly serving human clients reveals an apparently fundamental limitation on the capacity of automation to displace human labor. Humans may be retained to provide a communication link between variable and error-prone human customers or consumers, and an efficient but inflexible computer or other automatic system.

It seems reasonable to infer from this result that an increasing proportion of the service-sector labor force will be engaged in interfacing between fully automated machine systems and individual members of the public seeking the service. They will be interpreters between man and machine rather than actual producers. This constraint will set a lower limit on the manpower demands of the service sector however far automation progresses.* But this limitation is consistent with a major overall reduction in per unit labor requirement of the service sector due to computerization and related developments.

8.2.3 Advances in already automated processes

With two exceptions, labor productivity gains were small or nonexistent where the older technology was already free of detailed human manipulation, and could thus be described as already automated. This position can be reached anywhere in the manufacturing and service sector where direct contact with consumers is not required. Cases from our own sample were electricity generation with centralized control, and hydrocarbon cracking. In these cases technological change was undertaken either to secure improved productivity of capital equipment (electricity generation), or to obtain greater yield from raw materials (hydrocarbon cracking), reduction in labor input being a secondary consideration. In such instances any increase or decrease in labor requirement will be of minor proportions,and it seems from our results that decreases are about as frequent as increases.

Thus in general further technological change in highly mechanized industries may be expected to produce little change in total manpower demand.

8.2.4 Delayed labor impact of automation associated with reorganization of the plant level work force

There were two evident exceptions to this last generalization, both of considerable interest.

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*Though technology has certainly produced workable direct links between client and mechanism, notably the pervasive dial telephone system.

The first was the change from decentralized to centralized control of electricity generation. This is a case where the labor savings potentially obtainable from the previously implemented technological change from manual to automatic control had not yet been fully realized. Centralization of control entailed little or no change in the process technology as such, yet it permitted a major reorganization and rationalization of the associated work force. Thus the 54.4% productivity gain achieved here (indirect labor included) may be interpreted as a delayed consequence of automation. We ascribe it to an organizational change "potentiated" by existing technology, rather than to a genuinely new technological advance. Once centralized, the further, genuine, technological advance to partial computer control had a negligible effect on the labor force.*

More generally speaking, we conclude that the potential impact of automation on labor requirement may be delayed pending appropriate changes in the within-plant deployment of the workforce. Many other past and future instances of this phenomenon can be identified in contemporary industry.

8.2.5 Unattended operation and infinite overall labor productivity

The second exception was of a wholly different order. In the case study on computerization of an air-separation plant we observed an already highly automated process being placed under full control of a digital computer. The last human operator was withdrawn, and the process left completely unattended. In the newer technology the only human intervention required was passive monitoring of computer generated messages appearing on a teletype placed adjacent to a nearly manned plant, and weekly calibration of automatic measuring devices. This resulted in the elimination of one direct operator per shift, or four full-time-equivalent workers, which does not in itself represent a large labor saving. The bulk of the original labor requirement had actually been eliminated at a much earlier stage of process development.

The significance of this case lies not in the absolute manpower saving achieved but in the fact that the new technology shows extremely high, indeed almost infinite, overall labor productivity, since the production of large volumes of liquefied gas requires only a few minutes of direct human labor per week. But labor productivity becomes difficult to estimate reliably in this situation, and little significance can be attached to the measured increases of 1,850% (direct labor only) or 48% (overall). It is perhaps better to describe the situation as one where the production process has ceased to require human labor, and has therefore effectively withdrawn from the labor market.

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*But see footnote on page 147.

This state of near zero absolute labor requirement, equivalent to near infinite overall labor productivity, must be carefully distinguished from the one discussed below in connection with electricity generating plant, where there is a fixed labor demand of significant size regardless of volume of output. The latter case has near zero marginal rather than overall labor demand, or total inelasticity of labor demand relative to demand for the product.

There are as yet very few other cases comparable to this new unattended air-separation technology in the manufacturing sector, so that generalization would be premature. In the service sector there are unattended hydroelectric and gas-turbine power plants, fully automatic telephone exchanges, unattended radio and television studios and transmitters, vending machines, parking meters, laundromats, gas stations and many similar systems. From this it is clear that unattended operation is a well-established fact, but so far as we know, the impact of these and other similar technological developments on manpower demand has gone unremarked in the literature. No attempt has been made to estimate their aggregate statistical effect on the labor force, though it may well be substantial.

The significance of the air separation case lies mainly in the future, since the technological lead given by this success in unattended operation of a relatively simple manufacturing plant is likely to create the confidence needed to operate larger and more complex manufacturing and service processes unattended, causing an increasing and important decline in labor demand (gains in labor productivity) for industry and the economy as a whole.

Discussions with technological personnel in the various plants indicated that the technological threshold of readiness to leave major plants unattended is associated first with attaining satisfactory reliability of the digital computer and peripheral equipment, and then with gaining sufficient control of raw materials and the process environment, through development of computer control programs and other "software." The point must be reached where almost all conceivable exigencies can be handled by the computer program and associated mechanical equipment without human intervention.

The necessary confidence is gained quite slowly in most cases. It must reach a high level before unattended operation becomes an attractive proposition, since operating a large plant always entails risk of major loss, and labor cost is small in relation to capital investment. During our studies we observed many processes with their human crews operating at very low workload, effectively acting as an insurance against the remote chance of automatic control system failure or other rare contingency. As the labor cost--the "insurance premium"--is a small fraction of total cost at this stage, the incentive for management to take the final step to unattended operation is relatively weak.

Yet it may be taken for the following reason. With increasing program complexity, the detailed responses of the automatic equipment are often unintelligible to the operator and his intervention may disturb or disrupt rather than enhance process stability, reducing yield and product quality. Thus the cost of undesirable human intervention may exceed the benefit gained by insuring against low probability contingencies, and at this point unattended operation becomes distinctly attractive.

Among the processes we have studied, this point will be reached before long in hydro-carbon cracking and electricity generation, and there are undoubtedly many more computer-controlled processes nearing the same threshold.

Hence the overall expectation for the labor market is of a further reduction in labor demand per unit product, occurring fairly widely in process industry due to the transition to unattended digitally computer-controlled process operation. There will be a reduction in process operator type jobs. However, these anticipated changes are likely to affect relatively small numbers of workers in each of many industries over a long period, and no sudden major impact on the labor force if foreseen.

8.2.6 Effect of scale of automated processes; infinite marginal labor productivity

Apart from complete abolition of labor demand through digital process control leading to unattended operation, our sample processes also highlighted another well recognized and important trend in plant design which has in many ways a similar manpower impact. This is the effect of the physical size or scale of plant on labor productivity, seen in the background information of the case studies on steel-strip processes, electricity generation, hydro-carbon cracking and air separation rather than in the manhour data itself. In all these four cases, comparison between plants and firms showed that crews of fixed size could freely interchange between plants of varying size. The labor productivity of the process is then determined not so much by the technology as by the physical size (and hence throughput capacity) of its specific embodiment. Reducing output below capacity permits no (short run) reduction in manhour input, nor does increased output short of full capacity require extra manhour inputs.

We can describe this situation as one of infinite (short run) marginal labor productivity, or zero marginal labor demand, associated with non-infinite overall productivity. In these cases, direct production manhour demand for the industry as a whole will be determined by the aggregate number of units operating, while production depends on aggregate capacity. The consequence is a fixed labor force largely independent of demand for the product.

In this situation the economic trend is, of course, towards plants of larger and larger capacity, so that on average each such industry shows a downward trend in labor demand per unit product. This tendency is well known and needs no further discussion here, beyond remarking that in this phase of technological advance labor productivity figures must be treated with extreme caution, since one cannot assume elasticity of production with respect to labor supply.

The outlook, again, is for steadily decreasing aggregate labor demand per unit product, associated with steadily increasing average size of plant throughout process industry. The labor demand will depend on total capacity, being inelastic with respect to current demand for the product.

8.3 The Skill Impact of Technological Change (Qualitative Changes in Labor Input per Unit Product)

A major objective of the research was to demonstrate the occurrence of skill profile changes due to technological change under adequately statistical control, and using an experimental design capable of assessing the statistical confidence level of the observed changes. This was accomplished, for direct labor only, in a total of 8 sets of cases reflecting 8 types (and subtypes) of technological change. The results of the 11 resulting analyses of variance are summarized in Table 8.2. No change in skill profile was recorded for 2 subtypes of technological change, a highly significant change was found in 3 cases, while the remainder showed low to moderate significance levels.

We conclude that in the majority of cases technological change has a statistically demonstrable impact on direct labor skill demand.

The change in skill demand associated with technological change in our sample of processes was complex and cannot be adequately summarized in a single set of unqualified statements. We therefore present and discuss our overall conclusions from three different viewpoints, roughly corresponding to successive levels of disaggregation.

First, we consider changes in mean skill level computed from skill profiles for older and newer technologies; second we examine changes in the distribution of manpower demands by broad skill levels corresponding to tripartite grouping of job-evaluation scores in the skill profiles; and third, we examine changes in educational and training criteria adopted by employers to meet the skill requirements of their newer processes. A fourth area on which the field data presented in the various appendices could throw light is the manner in which specific human tasks, functions and job contents change with technology. This topic is not covered in the present report.

Before embarking on detailed discussion we wish to make three general comments bearing on the interpretation of the data presented. First, the reader is requested to keep the distinction between absolute and relative changes in skill demand clearly in mind. Since technological change usually entails change in overall labor requirement, the following situation can arise. A reduced absolute demand* for some specific level of skill or education may, if the total labor requirement is reduced more than proportionally, emerge as an increased relative demand for that skill level. Thus apparently opposite conclusions can be drawn by interpreting the same data in different ways; which is the more significant will depend on the nature of the policy or other question at issue, and since in this chapter we present a generalized discussion independent of specific policy options, both are given equal weight.

Secondly, the results and discussion deal with steady-state production processes in the manufacturing and service sectors of the economy as a whole. Our data collection procedures deliberately excluded labor demands attributable to non-steady-state productive activities such as capital construction, re-equipment, product improvement and the like, and a fortiori they also excluded such overhead activities such as in-plant training and education, maintenance of methods and standards, security, public relations, research and so on. The reader should bear this somewhat severe restriction in mind when considering the implications of the data for the whole of a specific industry or sector of the economy, still more for the entire economy.

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*Measured in manhours per unit product.

TABLE 8.2: STATISTICAL SIGNIFICANCE OF OBSERVED CHANGES IN DIRECT-LABOR SKILL PROFILE DUE TO TECHNOLOGICAL CHANGE

Technological Change	Process	Firms	Product Unit	Variance Ratio	Probability	Statistical Significance of Observed Change in Skill Profile
1. Machine-Aided Manual to Computerized E.D.P. in Banks	Check Processing (Ref. 1, pp. 11 & 24-41)	A, B	1000 Items	26.3 (2, 2 d.f.)	0.05	Moderately Significant
2. Batch to Continuous Processing	Annealing Steel Strip (Ref. 1, pp. 12 & 41-51)	C, D	10 Tons	21.4 (2, 3 d.f.)	0.05	Moderately Significant
	Coating Steel Strip (Ref. 1, pp. 12 & 51-62)	C, D	10 Base Boxes	16.2 (2, 3 d.f.)	0.025	Highly Significant
3. Conventional to Numerically Controlled Machining	Machining Aerospace Parts (Ref. 1, pp. 13 & 62-68)	E, F	1 Part	7.63 (2, 14 d.f.)	0.01	Highly Significant
4. Manual to Computerized Random Demand Real Time Service	Airline Reservations (pp. 124-143)	N, P	100 Passengers Boarded	4.63 (2, 14 d.f.)	0.10	Approaching Significance
5. Manual to Computer Process Control						
a) Mainly Closed-Loop	Electricity Generation (pp. 78-94)	J, K	10^6 KWH 1 Plant Operating Hour	No Change No Change	- -	No Change No Change
b) Partially Closed-Loop	Hydrocarbon Cracking (pp. 95-110)	G, H, I	1000 Barrels	No Change	-	No Change
c) Fully Closed-Loop	Air Separation (pp. 110-120)	L	10 Tons	Large Change (No Replication Available)	-	Highly Significant
6. Non-Centralized to Centralized Manual Process Control	Electricity Generation (pp. 45-74)	J, K	10^6 KWH 1 Plant Operating Hour	4.97 26.44 (2, 3 d.f.)	- 0.05	Not Significant Moderately Significant

Thirdly, the skill levels used are not strictly equivalent across industries and process types. Within each industry it was possible to set up an exact skill level metric based on abundant job evaluation data. Where two firms schemes differed in detail, we were able to cross-compare and utilize ratings by skilled job analysts to construct a single scale valid for two or more organizations. But comparisons across industries were hampered by lack of fully comparable "benchmark" jobs, and more fundamentally by lack of a truly universal measure of skill level.*

Lacking sound reference points, we endeavored to establish cross-industry comparability by subjective comparison of job descriptions across the six industries*, and we feel that the chance of serious error is small. More fully quantitative cross-comparisons might reveal minor discrepancies but would be unlikely to upset the conclusions presented below.

8.3.1 Technological change and mean skill level

Direct Labor

Initial and final mean skill levels, computed from job evaluation point scores† weighted by manhours per unit product, are summarized in Table 8.3 for the eighteen processes studied. Taken by individual case, eight processes, or nearly half the total, showed more than 5% increase in mean skill level, nine remained unchanged or nearly so (changes falling in the range ±5%), and one case showed a decline of 10%. Thus the prima facie evidence points to a general increase in the skill demanded of direct labor due to technological change.

Examining these changes in skill level averaged over processes within the six distinct types of technological change initially identified for study, we note substantial increases in four cases (E.D.P. in banks, continuous strip processing, computerized reservation system and centralized automatic control), one case (computer process control) with no change, and one (numerical control) showing a modest decline. Again we draw the overall conclusion that technological change is on the average associated with an increase in labor force skills.

At direct labor level we therefore find strong support for the widely-held view that current technological trends require upgraded direct labor force skills.

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*Appendix G.

†After suitable adjustment of factor scores to secure within-industry comparability.

Overall Labor Force

However, the addition of data on indirect labor (unfortunately available in suitable form for only 5 of the 18 processes) forces us to modify this conclusion. In the three single cases where hard data was available and the proportional contribution of indirect labor was high (steel annealing, electricity generation, air separation), the changes in mean skill level were markedly less for the composite data than for direct labor only. Assuming that indirect labor requirements and skill levels in the other steel-finishing and electricity generation processes were similar to the ones studied, that they were little affected by the technological change in hydro-carbon cracking*, and that indirect labor was relatively unimportant in the airline reservation systems†, we may plausibly conclude that in only two out of the six process types (demand deposit accounting and airline reservation systems) did the overall increase in mean skill level exceed 5%. This considerably modifies the conclusion based on the direct labor data alone.

Thus the two service-sector process types were the only ones where technological change produced skill upgrading large enough to be probably detectable in the aggregate labor demand statistics of the relevant industries.

There was distinct down-grading of skill demand due to technological change in centralized and computer-controlled electricity generation and in air separation, though probably too small to be detected in aggregate statistical data. This observation offers some support for Bright's contention that skill requirements decline (rather than increase) with automation. It will be recalled that while Bright's studies did not provide controlled comparative data of the type discussed here, his observations covered a wide range of metal working industries, most nearly paralleled here by the aerospace machining process where our results do not conflict with his.

8.3.2 Technological change and labor requirements by specific skill levels

On examining the detailed pattern of change in labor requirement per unit product at specific skill levels within the aggregate changes in mean skill level discussed above, the processes and process types studied showed marked differences.** For the

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[*] An assumption made plausible by the data presented in Table 8.5.

[†] Supported by collateral qualitative information from management.

[**] For a complete appreciation the reader should refer to the total set of skill profiles presented in the individual case studies.

TABLE 8.3: SUMMARY OF MEASURED CHANGES IN MEAN SKILL LEVEL

Technological Change	Sample Process	Industry	Product Unit	Direct Labor			Overall (Direct Plus Indirect)		
				Mean Score*			Mean Score		
				Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change
Machine-aided manual to computerized	Demand deposit accounting	Banking	1000 items processed	112.3 103.9	118.2 112.1	+ 9.8% +15.8%	187.3	222.0	+26.0%
Batch to continuous process	Annealing strip	Steel	10 tons	3.0 3.4	3.7 3.7	+23.3% + 8.8%	6.4	6.7	+ 4.7%
	Coating strip (galvanizing & tinplating)		10 tons 100 base boxes	2.4 3.3	3.6 3.2	+50.0% - 3.0%			
Conventional to numerically controlled machinery	Machining aircraft parts	Aerospace	1 part	585.4 623.8	579.2 595.4	- 2.5% -10.0%			
Decentralized to centralized control	Power generation	Electric utility	1 plant operating hr.	267.0 216.4	367.4* 386.7*	+43.8% +95.5%	314.2	296.8	- 6.3%
Conventional analog to digital computer process control									
Monitoring & performance calculations	Power generation	Electric utility	1 plant operating hr.	377.0 386.7	377.0* 386.7*	0.0% 0.0%	329.9	314.6	- 5.0%
Partially closed-loop	Hydro-carbon cracking	Oil	1000 barrels	368.6 368.6 436.7	368.6 368.6 436.7	0.0% 0.0% 0.0%			
Fully closed-loop	Air liquefaction & separation	Chemical	10 tons	160.0	160.0	0.0%	307.1	271.6	-11.6%
Semi-automatic to computerized random demand real time service	Airline passenger reservation systems	Air transportation	100 passengers boarded	280.5 251.5	322.9* 261.4*	+18.5% + 5.0%			

*These are recorded mean skill point scores. In computing percent changes the non-zero reference levels were first subtracted from mean skill level values at both technology levels. See reports of individual case studies.

present discussion the detailed data have been condensed by grouping into three broad skill levels, respectively Lower (roughly equivalent to "unskilled" labor), Medium ("semi-skilled" labor) and Higher (skilled craftsmen and above).*

Observed absolute manhour requirements grouped into these three levels are summarized for direct labor and overall labor respectively in Tables 8.4, and 8.5, and the same data are presented as proportions of total input for each process in Tables 8.6 and 8.7.

It will be noted that indirect labor data was available for only 8 of the 18 processes. Quantitative job evaluation scores were unavailable for 3 of these 8 (the 3 hydro-carbon cracking processes), so that mean skill levels could be computed for the total labor force in only 5 cases (see Table 8.3). However, we were able to assign the known manhours of indirect labor to broad skill groups in these 3 cases, so that some conclusions can be established relative to the overall skill distribution for this process type.

Lower Skill Levels ("Unskilled" Labor)

Considering direct labor first, only 5 out of 18 pre-change (older technology) processes required as much as 10% of their labor input in the lower skill levels (Table 8.6), and in 4 of these 5 cases this requirement declined steeply with technological change. The highest post-change proportion of lower skill level direct labor manpower was found in one of the two airline reservation systems, where the remaining low-skilled tasks were mainly routine clerical operations.† Another 4 of the 18 processes showed small increases in absolute and relative low level direct labor skill requirement associated with technological change.

When the indirect labor data are added, however, the resulting figures for the proportion of total labor input at lower skill levels fails to support the above conclusion, since there are strong signs (particularly in electric power generation and steel finishing) that when technological change displaces lower skills from the direct labor area, they reappear as indirect labor. Thus we note (Table 8.7) that the net change in the proportion of lower skills was almost zero when averaged over the 8 cases studied. But with a mean decline in total labor requirement, the absolute amounts of total lower-skilled labor per unit product decreased on average by a substantial amount.

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*A subjective appreciation of the levels of skills in question can be gained by referring to selected job descriptions presented in Appendix G.

†However in this case the job evaluation ratings are believed to have been biased downward, and some jobs, e.g., teletype operator, which were assigned to the lowest skill level should probably be reclassified "semi-skilled."

It seems plausible to draw the following conclusions concerning the overall consequences of technological change for unskilled labor. If a given process still requires a significant amount of unskilled labor in direct production work at the present time, technological change is likely to reduce this requirement substantially. But a fraction of it will probably reappear in the indirect labor area, leaving only a small net change. Modest new demands for unskilled labor seem also to be created by some technological changes, to some extent stabilizing the overall demand for lower-level skills. Extrapolating somewhat from these results we predict that unskilled labor will continue to account for some 5% of the total (direct plus indirect) production labor force despite further technological change.

Middle Skill Levels ("Semi-Skilled" Labor)

Again taking direct labor first, we note that pre-change (older technological level) demands for medium skill levels in the 18 processes varied all the way from 100% of the direct labor force (in demand deposit accounting) down to zero (in hydrocarbon cracking). All of the 15 cases with a non-zero pre-change medium level skill demand showed post-change reductions. These ranged from 100% to 3.6% of the total labor requirement.

Thus we may conclude with some assurance that technological change reduces direct labor demands for medium skilled labor both relatively and absolutely.

Considered by process type, and apart from the special case of air separation where the transition to unattended operation caused total elimination of medium skill requirements, the greatest reduction (31.6% of total labor requirement) occurred in centralization of control in electricity generation. Here the transfer from medium to high-level skill demands was clearly associated with more "concentrated" tasks, i.e., those covering a greater area of the process and equipment.

The pattern of change in the four steel finishing processes cannot be interpreted in this way, since the newer technology differed markedly from the old, and few of the new tasks were comparable in any direct way with the old ones. Here, and in the cases of demand deposit accounting and airline reservations, a substantial number of pre-change tasks requiring medium skill levels were abolished and replaced by somewhat fewer distinctly new tasks demanding higher skill levels.

Again the addition of indirect labor seems, for the 8 cases available, to dilute the overall effect of the technological changes. One case (centralization of electricity power generation)

TABLE 8.4: SUMMARY OF ABSOLUTE MANHOUR REQUIREMENTS PER UNIT PRODUCT BY SKILL LEVEL (DIRECT LABOR ONLY)

Technological Change	Sample Process	Industry	Product Unit	Manhours Per Unit Product								
				Lower Skill Levels			Medium Skill Levels			Higher Skill Levels		
				Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change
Machine-aided manual to computerized	Demand deposit accounting	Banking	1000 items processed	0.0	0.7	+ 0.7	30.3	12.9	-17.4	0.0	2.4	+ 2.4
				0.0	0.7	+ 0.7	21.5	14.7	- 6.8	0.0	1.6	+ 1.6
Batch to continuous process	Annealing strip	Steel	10 tons	0.1	0.0	- 0.1	1.6	0.9	- 0.7	0.6	0.4	0.0
				0.0	0.0	0.0	1.7	1.0	- 0.7	0.8	0.6	- 0.2
	Coating strip (galvanizing & tinplating)		10 tons	1.5	0.1	- 1.4	9.6	2.0	- 7.6	1.7	1.8	+ 0.1
			100 base boxes	0.2	0.1	- 0.1	7.6	1.6	- 6.0	3.1	1.2	- 1.9
Conventional to numerically controlled machinery	Machining aircraft parts	Aerospace	1 part	0.3	0.2	- 0.1	1.1	0.6	- 0.5	2.4	1.9	- 0.5
				0.1	0.2	+ 0.1	0.7	0.2	- 0.5	3.0	1.7	- 1.3
Decentralized to centralized control	Power generation	Electric utility	1 plant operating hr.	2.0	0.0	- 2.0	7.0	3.0	- 4.0	1.0	2.2	+ 1.2
				4.0	0.5	- 3.5	5.0	1.0	- 4.0	0.3	3.0	+ 2.7
Conventional analog to digital computer process control												
Monitoring & performance calculations	Power generation	Electric utility	1 plant operating hr.	0.0	0.0	0.0	2.0	2.0	0.0	2.0	2.0	0.0
				0.5	0.5	0.0	1.0	1.0	0.0	3.0	3.0	0.0
Partially closed-loop	Hydro-carbon cracking	Oil	1000 barrels	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	0.0
				0.0	0.0	0.0	0.0	0.0	0.0	3.5	3.5	0.0
				0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	0.0
Fully closed-loop	Air liquefaction & separation	Chemical	10 tons	0.0	0.0	0.0	3.7	0.0	- 3.7	0.0	0.0	0.0
Semi-automatic to computerized random demand real time service	Airline passenger reservation systems	Air transportation	100 passengers boarded	6.4	0.6	- 5.8	87.5	37.9	-49.6	33.1	39.7	+ 6.6
				35.0	22.3	-12.7	85.2	54.7	-30.5	79.0	66.5	-12.5

TABLE 8.5: SUMMARY OF ABSOLUTE MANHOUR REQUIREMENTS PER UNIT PRODUCT BY SKILL LEVEL (DIRECT AND INDIRECT LABOR)

Technological Change	Sample Process	Industry	Product Unit	Manhours Per Unit Product								
				Lower Skill Levels			Medium Skill Levels			Higher Skill Levels		
				Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change
Machine-aided manual to computerized	Demand deposit accounting	Banking	1000 items processed	0.0	0.7	+0.7	30.3	12.9	-17.4	4.5	4.1	-0.4
Batch to continuous process	Annealing strip	Steel	10 tons	0.2	0.2	0.0	1.9	1.3	- 0.6	1.5	1.8	+0.3
	Coating strip (galvanizing & tinplating)		10 tons 100 base boxes	Data not available			Data not available			Data not available		
Conventional to numerically controlled machinery	Machining aircraft parts	Aerospace	1 part	Data not available			Data not available			Data not available		
Decentralized to centralized control	Power generation	Electric utility	1 plant operating hr.	5.1	2.3	-2.8	10.3	7.8	- 2.5	7.3	4.7	-2.6
Conventional analog to digital computer process control												
Monitoring & performance calculations	Power generation	Electric utility	1 plant operating hr.	1.3	1.9	+0.6	4.6	4.8	+ 0.2	4.4	4.7	+0.3
Partially closed-loop	Hydro-carbon cracking	Oil	1000 barrels	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	4.2 3.7 6.2	4.4 3.8 6.6	+0.2 +0.1 +0.4
Fully closed-loop	Air liquefaction & separation	Chemical	10 tons	0.0	0.0	0.0	0.7	0.7	0.0	0.3	0.1	-0.2
Semi-automatic to computerized random demand real time service	Airline passenger reservation systems	Air transportation	100 passengers boarded	Data not available			Data not available			Data not available		

TABLE 8.6: SUMMARY OF DISTRIBUTION OF MANHOUR REQUIREMENTS BY SKILL LEVEL

Technological Change	Sample Process	Industry	Product Unit	Proportion of Total Direct Labor Manhours at								
				Lower Skill Levels			Medium Skill Levels			Higher Skill Levels		
				Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change
Machine-aided manual to computerized	Demand deposit accounting	Banking	1000 items processed	0.0 0.0	4.4 4.1	+ 4.4 + 4.1	100.0 100.0	80.6 86.5	- 19.4 - 13.5	0.0 0.0	15.0 9.4	+15.0 + 9.4
Batch to continuous process	Annealing strip	Steel	10 tons	4.8 0.0	0.0 0.0	- 4.8 0.0	76.2 68.0	69.2 62.5	- 7.0 - 5.5	19.0 32.0	30.8 37.5	+11.8 + 5.5
	Coating strip (galvanizing & tinplating)		10 tons 100 base boxes	11.7 1.9	2.6 3.4	- 9.1 + 1.5	75.0 69.7	51.3 55.2	- 23.7 - 14.5	13.3 28.4	46.2 41.4	+32.9 +13.0
Conventional to numerically controlled machinery	Machining aircraft parts	Aerospace	1 part	7.9 2.6	7.4 9.5	- 0.5 + 6.9	28.9 18.4	22.2 9.5	- 6.7 - 8.9	63.2 79.0	70.4 81.0	+ 7.2 + 2.0
Decentralized to centralized control	Power generation	Electric utility	1 plant operating hr.	20.0 43.0	0.0 11.1	-20.0 -31.9	70.0 53.8	57.5 22.2	- 12.3 - 31.6	10.0 3.2	42.3 66.7	+32.3 +63.5
Conventional analog to digital computer process control												
Monitoring & performance calculations	Power generation	Electric utility	1 plant operating hr.	0.0 11.1	0.0 11.1	0.0 0.0	50.0 22.2	50.0 22.2	0.0 0.0	50.0 66.7	50.0 66.7	0.0 0.0
Partially closed-loop	Hydro-carbon cracking	Oil	1000 barrels	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	100.0 100.0 100.0	100.0 100.0 100.0	0.0 0.0 0.0
Fully closed-loop	Air liquefaction & separation*	Chemical	10 tons	0.0	0.0	0.0	100.0	0.0	-100.0	0.0	0.0	0.0
Semi-automatic to computerized random demand real time service	Airline passenger reservation systems	Air transportation	100 passengers boarded	5.0 17.6	0.8 15.2	- 4.2 - 2.4	69.0 42.8	48.4 39.2	- 20.6 - 3.6	26.0 39.6	50.8 45.6	+24.8 + 6.0
Averages				7.4	4.1	- 3.3	49.6	39.8	- 9.8	43.0	56.1	+13.1

*Not included in averages.

TABLE 8.7: SUMMARY OF DISTRIBUTION OF MANHOUR REQUIREMENTS BY SKILL LEVEL (OVERALL LABOR MANHOURS)

Technological Change	Sample Process	Industry	Product Unit	Proportion of Total Overall (Direct and Indirect) Labor Manhours at:								
				Lower Skill Levels			Medium Skill Levels			Higher Skill Levels		
				Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change	Older Tech.	Newer Tech.	Change
Machine-aided manual to computerized	Demand deposit accounting	Banking	1000 items processed	0.0	4.0	+4.0	87.1	72.9	-14.2	12.9	23.1	+10.2
Batch to continuous process	Annealing strip	Steel	10 tons	5.6	5.2	-0.4	51.6	38.9	-12.7	42.8	55.9	+13.1
	Coating strip (galvanizing & tinplating)		10 tons 100 base boxes	Data not available			Data not available			Data not available		
Conventional to numerically controlled machinery	Machining aircraft parts	Aerospace	1 part	Data not available			Data not available			Data not available		
Decentralized to centralized control	Power generation	Electric utility	1 plant operating hr.	22.5	15.5	-7.0	45.4	52.7	+ 7.3	32.1	31.8	- 0.3
Conventional analog to digital computer process control												
Monitoring & performance calculations	Power generation	Electric utility	1 plant operating hr.	12.6	16.7	+4.1	44.7	42.1	- 2.6	42.7	41.2	- 1.5
Partially closed-loop	Hydro-carbon cracking	Oil	1000 barrels	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	100.0 100.0 100.0	100.0 100.0 100.0	0.0 0.0 0.0
Fully closed-loop	Air liquefaction & separation	Chemical	10 tons	0.0	0.0	0.0	70.0	87.5	+17.5	30.0	12.5	-17.5
Semi-automatic to computerized random demand real time service	Airline passenger reservation systems	Air transportation	100 passengers boarded	Data not available			Data not available			Data not available		
Averages				5.1	5.2	+0.1	37.4	36.8	- 0.6	57.6	58.1	+ 0.5

exhibited a relative but not an absolute increase in medium-level skills. Thus there seems again to have been a displacement of medium level skills from the direct into the indirect labor force, together with an absolute decrease in medium-level skill requirements.

High Skill Levels ("Skilled" Labor)

The pre-change direct-labor demand for high level skills varied from all to none of the labor force (Table 8.6). In the former case, comprising 3 processes, naturally no increase could occur. Of the remaining 15 processes, 12 showed an increase.

Thus the generalized conclusion is warranted that technological change increases the relative proportion of top-level skill requirements for direct labor. But as seen in Table 8.4, only 5 of these 12 cases represented an absolute increase in requirement per unit product, while 4 showed decreases, and three were almost unchanged. Thus the productivity of higher-level skills (the volume of product per unit of highly skilled labor power utilized) clearly did increase to some extent with technological change, though less than total labor productivity.

When indirect labor is included (Tables 8.5 and 8.7) we have results from 8 processes. These show fewer increases in proportional higher-skilled labor demand, only 2 out of 8 being large enough to be considered major. And none show significant increases in absolute higher-level skill demand. Contrasted with the direct labor data, this pattern suggests that there has been a net transfer of higher-level skills out of indirect into direct labor demands, once again diluting the net impact of the technological change on the labor force, but in the reverse direction to that observed at lower skill levels.

We conclude that technological change generally reduces the absolute demand for skilled labor, hence that the productivity of skilled labor considered in isolation is somewhat increased by automation. In general we infer that the overall tendency toward skill upgrading is largely accounted for by labor economies at semi-skilled ("operative") and to a lesser extent at unskilled ("laborer") levels, with little net contribution by increases in higher skill levels.

Considered by process-type, in the 3 computer process control applications respectively, all, half, and none of the pre-change labor force was at a high skill level, and the post-change situations were identical. Here there was a uniform small absolute increase in skilled labor for the total labor force (Table 8.5), due presumably to the addition of maintenance labor required to service the new computer and peripheral equipment. In all other cases the post-change direct labor force (Table 8.6) contained a greater proportion of higher skill levels than the pre-change one, and except in one case this was maintained (Table 8.7) after the inclusion of indirect labor.

But three of the six process types (continuous processing, numerical control and computerized RDRT systems) showed decreases in absolute per unit demand for direct labor at these higher skill levels (Table 8.4). The two process types showing absolute direct labor increases at highly skilled level are of special interest. They were computerized off-line data processing (demand deposit accounting) and centralized control of electric power generation. The former is a case where substantial amounts of new complex equipment were introduced to supplant previous largely self-supervising manual workers, and new higher skilled workers were required to operate it. They are mainly employed on evening and night-shift work, while the day-shift labor force remains medium-skilled. Here the addition of indirect labor revealed a counterbalancing reduction, apparently due to the reduced need for supervision of the reduced direct labor force, and the net result was a small decline in higher-level skill requirements.

The latter case--centralized control of electric power generation--is one where skills were upgraded through what may be called "job-enlargement," the combination of previously separate direct tasks into new, more complex, and therefore higher-skilled, jobs. This upgrading process is made feasible by relocating what had been widely separated control stations into a central control room. But again there was a counterbalancing reduction at indirect labor level, leaving a net downward change in higher-level skill requirements.

In the case of computerized RDRT services (airline reservation system) new complex equipment was introduced without a concurrent increase in higher skill labor requirements. Direct labor data only are available, and the skill distributions for the second firm in which this process type was studied are of somewhat doubtful validity, due to shortcomings in the job evaluation data. Thus it may be better to take the first firm as definitive. The result here is in line with those discussed above, showing small absolute and relative increases in higher skill requirements. The amount of indirect labor is probably small in this case, so this probably represents the true overall picture.

8.3.3 Summary of conclusions on the skill impact of technological change

Given the complexity of the picture presented above, any attempt to summarize the results is liable to be misleading. Nevertheless the following very broad conclusions appear to be warranted.

First, there was little or no overall net tendency for the mean skill level of the workforce to increase with technological change. An upward tendency shown by the direct labor data seems to have been due to incomplete observation, since in many cases pre-direct change direct labor demands for lower level skills reappeared as indirect labor demands after the change. The phenomenon makes it imperative to include at least the major components of indirect labor in any future comparative study of the mnapower impact of technological change.

Second, the small overall changes in mean skill levels were largely offset by larger overall productivity increases. Hence decreases in absolute demand measured in manhours per unit of production for specific skill brackets were more prevalent than increases.

The decreases in absolute labor demand were greatest at middle levels ("semi-skilled"labor), next greatest at unskilled levels (laborers), and least for skilled labor (operatives and skilled craftsmen). The data suggest almost no net change in the last case.

Third, when examined by type of process, major changes in skill demand are found to be concentrated in those cases--a majority--where what may be called primary automation and its consequences have not already been established. Technological change has relatively little manpower impact in already automated but still manned processes. The transition to what we may term secondary automation--where the process is turned over to full computer controland operates unattended--causes, as may be expected, a very large percentage decrease in manpower input, associated with a decline in skill-level; but this phenomenon is still rare in manufacturing industry.

Finally it must be said that, with the single exception of the transition to unattended operation, none of the manpower consequences of the technological changes studied appear major when evaluated as percentage changes of manhour and skill level demand. One would be confident of detecting few of the effects at a higher level of aggregation. Thus we conclude that technological change, as represented by this cross section of eighteen processes drawn from six process types, does not cause any major change in skill requirements. There is a perceptible upward drift in aggregate mean skill level, but no more.

8.4 Work Force Educational Levels

While our attention was primarily focused on job evaluation factor scores and on manhours of labor requirement to permit the above detailed analysis of the skill impact of technological change, where possible we also acquired collateral data on educational qualifications, training and job experience, as well as job descriptions for all the cases studied.* General conclusions cannot be drawn from training and job experience data (presented in the relevant appendices) with any confidence, but educational levels seem worth a brief discussion. The relevant data are summarized (for direct labor only) in Table 8.8. Each figure represents the mean of two or more firms.

In interpreting the figures, the reader should bear in mind that few, if any, of the recorded requirements for educational levels represent strict managerial recruitment criteria. Most are estimates, ventured by management, of the general educational level needed for success in the jobs in question, and many represent desired rather than strictly necessary attainments.

As to the results presented in Table 8.8, it will first be noted that no definite requirements beyond high school graduation were encountered. In cases where 100% of the labor force were quoted as needing the high school diploma, other things being equal there would undoubtedly be a preference for applicants with some college education. But this does not imply a requirement for education beyond the stated level.

With the one exception noted below, the newer technology required a better educated labor force than the old in each case, though differences were small, and the general nature of the process had more effect than the technological change itself. In demand deposit accounting the upward trend was slight, and partially offset by the addition of a small proportion of low educational requirement labor (corresponding to the unskilled labor discussed in the previous section). In the steel finishing processes, a new requirement for high school graduate level labor was ascribed mainly to the need to recruit for later promotion to foreman and above, after in-plant experience.

In centralized control of electric power generation, operators need facility in written communication, calculation, use of technical documents, and some ability to conceptualize the process, hence a near 100% requirement for high school graduate education was encountered. Similar remarks apply to hydrocarbon cracking processes. The need to fill the promotion ladder was also stressed in this case.

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*These are omitted from the present report for reasons of space and may be obtained from the authors on demand.

TABLE 8.8: SUMMARY OF DISTRIBUTION OF MANHOUR REQUIREMENTS BY EDUCATIONAL LEVEL (DIRECT LABOR ONLY)

Technological Change	Sample Process	Industry	Product Unit	Proportion of Direct Labor Manhours Requiring:					
				No High School		Some High School		High School Diploma	
				Older Tech.	Newer Tech.	Older Tech.	Newer Tech.	Older Tech.	Newer Tech.
Machine-aided manual to computerized	Demand deposit accounting	Banking	1000 items processed	0.0	3.9	43.1	36.0	56.9	60.1
Batch to continuous process	Annealing strip	Steel	10 tons	64.8	61.8	35.2	19.1	0.0	19.1
	Coating strip (galvanizing & tinplating)		10 tons 100 base boxes	88.4	68.1	11.6	22.4	0.0	9.5
Conventional to numerically controlled machinery	Machining aircraft parts	Aerospace	1 part	1.3	33.2	0.0	0.0	98.7	66.8
Decentralized to centralized control	Power generation	Electric utility	1 plant operating hr.	10.4	0.0	0.0	0.0	89.6	100.0
Conventional analog to digital computer process control									
Monitoring & performance calculations	Power generation	Electric utility	1 plant operating hr.	0.0	0.0	0.0	0.0	100.0	100.0
Partially closed-loop	Hydro-carbon cracking	Oil	1000 barrels	0.0	0.0	0.0	0.0	100.0	100.0
Fully closed-loop	Air liquefaction & separation	Chemical	10 tons	100.0	*	0.0	*	0.0	*
Semi-automatic to computerized random demand real time service	Airline passenger reservation systems	Air transportation	100 passengers boarded	Data not available		Data not available		Data not available	

*No direct labor requirement in newer technology

The exception was numerical control, where about one third of the post-change labor force needed no high school education. This was because the need to read and interpret engineering and drawings and technical instructions had been partially eliminated with the adoption of preprogrammed tape control.

Finally, the special case of air separation may be noted. Here the pre-change operator, a single man per shift, required little education, depending almost entirely on in-plant experience. There were no post-change operators.

CHAPTER 9: POLICY IMPLICATIONS

We now consider the implications of our results for manpower and economic policy. Here we move beyond the relatively firm ground of observations and factual inferences into areas requiring broad vision and judgment to synthesize many diverse aspects of the policy issues. As a research team specializing in a particular subfield of manpower research, we do not claim particularly broad vision. Therefore the following discussion must be read as a specialist contribution to the formation of policy. As Professor Galbraith has pointed out in his recent study of "The New Industrial State," the fate of such specialist contributions is to be probed and tested for validity, then integrated with other analyses so that executive policy can ultimately be formed from the confluence of many sources of information and competing analyses.

The field of manpower policy has been very fully discussed in the post World War II literature, especially in the seven years since MDTA*, and the present chapter would be overloaded by any attempt to provide a review doing even partial justice to the numerous distinguished contributions. Therefore the reader is assumed to be familiar with the main lines of the various interlocking issues and debates in progress, and we examine only those questions to which our results are particularly relevant.

Brief overviews of manpower policy goals, the place of manpower policy within broader economic and social field, and the structure of what may be termed the "manpower subsystem" of the economy, will be given first to provide a framework and establish terminology. Within this framework specific discussions of the following topics follow: structural changes in manpower demand and unemployment related to technological change and short-term training and retraining policy; longer-term vocational training and educational policy; the impact of technological change on full-employment policy, particularly as implemented by fiscal and other measures to maintain aggregate demand; and on further research and statistical needs in the manpower field.

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*A partial list runs to some 20 substantial volumes by non-Government sources, not to mention numerous official papers and reports.

9.1 The Framework of Manpower Policy

9.1.1 Policy goals

It is generally agreed that in an advanced industrial society such as the United States, manpower policy must be closely integrated with general economic and business policy. As the present Commissioner of Labor Statistics has put it*:

> "The manpower program can be viewed as one arm of national employment policy - the other arm being fiscal and monetary decisions that affect the level of aggregate demand. The central theme of manpower policy is, therefore, determined by the employment objectives of the government, to the extent that they are taken seriously."

Within this framework manpower and employment policy-makers pursue three distinct goals. First they seek to maximize the utilization of human labor and skill engaged in the production of goods and services, hence maximizing aggregate real income. Second, they aim to minimize the number of people underemployed or unemployed and so deprived of a meaningful place in society. And third they endeavor to secure equitable distribution of income according to current standards of social justice. The interaction of these and other policy goals has been well discussed by R.A. Gordon** who expresses the overall objective as the maximization of a "national economic welfare function" subject to various constraints. Full quantitative analysis along these lines becomes exceedingly complex and requires very careful definition of variables and relationships to avoid confusion.

9.1.2 Policy instruments and the "manpower subsystem"

The Labor Market

At present the manpower resources of the American economy are very largely allocated to productive uses by the free interplay of supply and demand controlled by pricing in the labor market.

On the demand side are industrial firms, government agencies, educational, military, research, and other organizations, together with unorganized individuals seeking personal services. The quantitative level and qualitative distribution (structure) of manpower demand at any given time is largely determined by the interaction of two specific factors, (i) the volumes of demand for various goods and services, and (ii) the technologies used for production to meet the demand for goods and services. The present research project was concerned with the latter factor, and the main policy implications of our findings are therefore on the structural aspect of the demand side of the labor market. In particular we have provided detailed new information on structural changes in manpower demand due to technology, with significant policy implications presented in Sections 9.2 and 9.3 below.

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* "Rhetoric and Reality in Manpower" in Manpower Tomorrow: Prospects Priorities, ed. Irving H. Siegel. New York: Siegel, 1967.

**R.A. Gordon, "Full Employment as a Policy Goal" in *Employment Policy and the Labor Market*, ed. A.M. Ross. Berkeley: University of California Press, 1965.

On the supply side of the labor market we recognize, in order of decreasing immediacy, individual unorganized members of the labor force, labor unions, public and private vocational training schemes and establishments, schools and colleges, and the family and social structure of society as a whole. Our own data have little to say about manpower supply at any of these levels and here we rely on the findings of other analysts.

Both the demand and supply sides of the labor market are quite highly structured at the level of the organization. Most industrial firms and corporations operate deliberate manpower policies designed to ensure continuing supplies of labor in the amount and quality needed for their production and other processes. However, each organization operates in the labor market to a large extent independently of others, particularly in negotiations with individual workers and labor unions. Firms and government organizations manage their own manpower supply internally by reallocation and promotion of individuals, together with inhouse education and training schemes. Thus the organization is the basic entity operating on the demand side of the labor market.

On the supply side a few employee organizations, such as labor unions, make deliberate attempts to coordinate the supply of specific anticipated labor demands. At a higher level, conscious mutual adjustments between individual firms needing labor and specialized educational and training organizations geared to supply it, are much less prevalent.

A major factor reducing the power of manpower demand to influence supply is the long lead-time needed to generate a specific type of human skill or experience in response to a new demand. Quantitative adjustments can be accomplished by short-term programs such as recruitment through local and national advertizing, and minor qualitative ones through in-house refresher courses, job-training and the like. More basic changes in labor force location, motivation and skill patterns require costly long-term educational and training efforts lasting up to five or more years per individual worker. Buoyant demand in the labor market encourages what in effect is long-term investment in human capital, but, being tied to individuals, this investment cannot be tightly controlled as in the case of physical capital. Therefore the process tends to be slow and diffuse in its response to new manpower demands. In general, the demand side of the market tends to assume inelastic supply, and there is much bidding-up of scarce manpower resources, principally ability, skills and experience. Our present findings on the impact of technological change appear to imply a need for federally supported longer-term apprenticeship and training programs to meet the future manpower needs of advanced manufacturing and service technologies. These are set out in Section 9.3 below.

Aggregate Demand as a Full-Employment Policy Instrument

It is now accepted that near-full employment requires a specific level of aggregate demand; below this level there will be a lack of job opportunities, while above it (following A.W. Philips' analysis) the rate of increase in wage rates will be unacceptably high.* In recent years governments have generally been able to stabilize aggregate demand at or near the target level by fiscal and/or monetary measures, thus maintaining near-full employment, generally with a small to moderate rate of inflation.

The efficacy of this demonstrably successful approach to full-employment policy depends on the operation of several dynamic causal sequences, among them a strong positive impact of aggregate demand on aggregate employment. This positive relationship has been taken for granted by all analysts,and is undoubtedly a real feature of the present situation. However, our investigation of the role of labor in modern technology leads us to conclude that this particular relationship is currently weakening and may be expected to break down in the not too distant future. When this occurs it will no longer be feasible to control aggregate employment solely by manipulating aggregate demand through fiscal or monetary policy. Additional policy instruments for maintaining full employment will then be called for.

This conclusion, explained more fully in Section 9.4, may be expressed in technical terms as follows. The marginal elasticity of demand for labor with respect to production shows signs of falling off and ultimately reaching zero. When this point is reached demand for labor will become functionally independent of demand for goods and services and will thus cease to respond (indirectly) to fiscal and monetary adjustments, the instrument on which most reliance is currently placed. It is suggested that this tendency will require major changes in full-employment policy.

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*See, J.W. Garbarino, "Income Policy and Income Behavior" in Employment Policy and the Labor Market, ed., A.M. Ross. Berkeley: University of California Press, 1965.

Income Distribution

Equitable income distribution according to current standards of social justice is achieved partly by maintaining full employment as discussed above, and partly by applying a mixture of fiscal and welfare policies designed to redistribute income, or whose unintentional effect is to do so. Since our data have no direct bearing on this aspect of manpower policy,* this aspect of manpower policy will not be discussed further.

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*Though indirect policy implications may be traced both through full-employment policy and through structural changes in manpower demand due to technological change.

9.2 Short-Run Manpower Supply Policies Related to Technologically Induced Changes in Manpower Demand

As noted in the previous section, our findings relate principally to the demand side of the labor market, and concern the impact of technological change on the quantity and quality of labor required for production and service processes. We now consider their specific bearing on short-run active manpower policies.

It has been suggested that Federal and State authorities should intervene on the supply side of the labor market to remove structural barriers to full employment created by technological change. Specifically, training and retraining schemes have been advocated to meet the supposedly higher skill-demands of automation, and as is well known, many such programs have been initiated. However, we have found very little evidence that technological change actually does result in novel or higher skill demands, and we therefore conclude that Federal and State training and retraining programs cannot be justified by the need to adjust the labor-supply skill mix to the requirements of newer technologies. Since the new skill demands are not markedly different from the old ones, there is no reason to suppose that normal (private and local) adjustment mechanisms will not continue to operate satisfactorily without government assistance. A more detailed discussion follows.

Automation and Structural Unemployment

In the upsurge of concern over the apparent impact of automation expressed in a voluminous literature of the late 1950's and early 1960's, some observers expressed anxiety almost amounting to panic over the reported loss of jobs and escalation of skill demands due to automation. Several analysts, with C.C. Killingsworth prominent among them,* cited technological change and particularly automation as being responsible for high unemployment rates. Major importance was ascribed to the supposed elimination of low-skill jobs leading to lack of opportunities for low-skilled workers, particularly youth and minority groups. It was suggested, in short, that automation had already produced a substantial volume of "structural" unemployment and would produce more. This position was reached despite the fact that Bright's field studies,** at that time the only substantial investigation bearing directly on changes in manpower demand due to technological change, failed to provide evidence of important skill upgrading, and indeed indicated a possible decline in skill demand. Possibly due to imprecise measurement and lack of adequate statistical control, Bright's field data may not have been considered conclusive enough.

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* C.C. Killingsworth in The Nation's Manpower Revolution, U.S. Senate Committee on Labor and Public Welfare, 1963.

**J.R. Bright, Automation and Management, Boston Harvard Business School, 1958.

Subsequent less heated discussion both revealed the paucity of hard data underlying the automation scare*, and showed how difficult it was to evolve a sound operational test for the existence of rigid structural factors preventing full employment. According to Lipsey**, structural barriers to full employment must be regarded as relative, not absolute, finding expression through inflation as expressed in the Philips' curve rather than having unemployment as a direct consequence. Lipsey postulated that structural factors would operate as follows. Progressively less productive elements of the (potential) labor force would enter employment as aggregate demand rose; the resultant loss of efficiency would cause cost increases, which in turn would lead to unacceptable inflation, the latter being the ultimate (indirect) limiting factor on aggregate employment. Also a prolonged period of high aggregate demand would permit further marginal elements to be gradually absorbed, causing a slow downward drift in unemployment rates. At the time of writing† the unemployment rate stands at a ten-year low of 3.3% after eight years of economic expansion, lately with significant inflation; Lipsey's general analysis thus appears to have been borne out by experience. Nevertheless it is clear that, while their impact is indirect, structural barriers to full employment do exist, since with an ideal labor force, and given the current high level of aggregate demand, unemployment would certainly be well below the present figure. The unexpectedly large extent of underemployment revealed in recent surveys by the Department of Labor†† also corroborates this view by showing that many labor force participants cannot find adequate work opportunities, even though aggregate demand is at or near its inflationary limit.

Our own findings show that technological change does not affect the structure of labor demand to any marked extent; and therefore confirm Bright's tentative conclusions and support Lipsey's indirect denial of the "strong" form of the structural unemployment hypothesis. While our earlier direct labor data pointed to a definite rise in mean skill level, the present results‡, providing a more balanced view of the total process-related labor force, show only very modest changes in skill profile and almost no increase in mean skill level. The latter is probably the best single index of the structural impact of technological change on labor demand.

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* e.g., C.E. Silberman, The Myths of Automation, 1966.

** R.G. Lipsey, "Structural and Deficient-Demand Unemployment Reconsidered" in Employment Policy and the Labor Market, ed., A.M. Ross, Berkeley: University of California Press, 1965.

† Early 1969.

†† See Chapter 1.

‡ See Tables 8.2 through 8.7.

Also we failed to find indications that labor supply is inadequately matched to demand, which would be expected to result in implementation of technological change being obviously delayed or hindered by shortages of skilled manpower. While in almost all cases the new job contents were markedly different from the older ones, we ascertained that local manpower supply adjustments (including recruitment, reallocation and retraining within the firm and on the job) had readily allowed the existing labor force to meet the new requirements. Many other case study reports support this conclusion.*

Indeed in some cases exactly the reverse effect to that postulated by the structuralist school was observed, for an avowed objective of technological change is to reduce dependence on the supply of skilled manpower, thus reducing structural barriers to full employment. For instance, our own studies on numerical control**, and others reported in the literature†, showed that a prime factor in the decision to install the new technology was management's wish to eliminate part of the need for skilled journeyman machinists, who were in short supply.

Explanation for Lack of Change in Skill-Profile

The reason for the non-appearance of major skill-upgrading despite the introduction of new and often highly complex equipment‡ is not far to seek. When deciding whether or not to install a proposed new technology, management takes the anticipated new manpower requirements into account. A new process with markedly higher skill demands will not be installed unless management is assured of an adequate supply of higher-skilled workers, a resource which is often conspicuous by its absence. Many potential new technological developments are therefore stillborn due to manpower supply constraints, but those that actually reach the fullscale planning stage are likely to conform to manpower supply constraints. The technical literature reports many instances where

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[*] e.g., Manpower Planning to Adapt to New Technology at an Electric and Gas Utility, B.L.S. Report #293, 1965; and
Studies of Automatic Technology - A Case Study of a Large Mechanized Bakery, B.L.S. Report #109, 1956.

[**] Crossman, E.R.F.W., S. Laner, L.E. Davis, and S.H. Caplan, op. cit. and
The Impact of Numerical Control on Industrial Relations at Plant Level --U.S.A., prepared for the Automation Unit, International Labor Office, Geneva, by E.R.F.W. Crossman, S. Laner, S. Caplan, 1968.

[†] Management Decisions to Automate, Manpower/Automation Research Monograph #3, Manpower Administration - Office of Manpower Automation and Training, 1964.

[‡] Described in Appendices 1-4.

projects were either never implemented, or delayed, or abandoned after startup, because of manpower supply problems.

Equipment designers and plant engineers are also required to ensure as far as possible that new equipment is operable and maintainable by existing staff with only minor retraining. Manpower plans are laid before new equipment is delivered; while a few key technical personnel may be allocated to specialist roles on the new process, overall skill demands are not generally permitted to increase significantly for fear of delays and shutdowns due to lack of the requisite skilled personnel.

Adjustments to reduced demand for lower-skilled labor are most frequently made without firing the individuals affected, by reallocation and planned attrition of the labor force. If this is fully effective there will be no new hiring despite increased production. Hence, due to deliberate organizational policy, only a modest change in skill profile is likely to be associated with introduction of a new technology, and, except where a new plant is located far from existing facilities, it generally has little immediate effect on external labor demand.

We cannot at present buttress this explanation of our data with hard evidence, but extensive field observation and discussion with managers, system designers and other technical personnel, together with study of the literature, gives us considerable confidence in its general correctness.

Implications for Training and Retraining Policy

The policy implications of this pattern are easily seen. Since organizations are well able to cope with the manpower consequences of technological changes (even major ones) by internal readjustment, they need no external help to supply higher-skilled workers or to re-employ lower-skilled ones. Nor should technological change be expected to affect the general labor market by causing rapid release of numerous redundant lower-skilled workers. At most there will be a prolonged "standstill" period of non-hiring at lower and middle-skill levels when a given technological change is unaccompanied by major expansion. A general consequence of this is that new entrants to the labor market, particularly unskilled youth and minority-group workers with few educational qualifications, cannot expect to find job opportunities in advanced manufacturing and service industries† and must therefore be absorbed by other sources of labor demand.

Highly organized services to the consumer may be a possible exception. In this case expanded capacity in data processing, communication and transportation may call for more extensive dealings with clients and require increased numbers of middle-level skilled workers to provide the interface between customer and system. The bank teller and airline sales agent* exemplify this class of occupation. We may note in passing that occupants of these consumer/system interface roles perform best when dealing with consumers of similar cultural backgrounds. Hence, as banking, transportation and other highly organized services spread to lower socio-economic and minority groups in the community, recruitment of middle-skilled members of racial and other minority groups might be expected to increase to fill these positions. Again, we have no evidence that private industry fails to meet these staffing needs though normal recruitment and internal training mechanisms, and no special Federal or State action seems necessary.

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*Whose roles are described respectively in Appendix 1 and Appendix 4 below.

†A phenomenon sometimes referred to as "silent firing".

To summarize the foregoing section, we find no indications that active manpower policies are needed to match labor supply to changes in process-related skill demands due to technological change. The requisite manpower adjustments fall well within the capability and motivation of organizations undergoing technological change, and should be left to them.

9.3 Long-Run Training and Educational Policy in Relation to Technology

As the previous section showed, the implications of our results seem to be largely negative for short-term Federal and State job training and retraining programs. We have found little or no evidence that these are directly required to facilitate short-run labor force adjustment to technological change. We have further suggested that the major reason for the unexpectedly small manpower impact of large and important technological changes is managements' ability to stabilize manpower demands at the design stage of a proposed new process or system. In short, our findings indicate that managements adjust technology to manpower supply, rather than manpower supply to technology.

This explanation of the data, though perhaps insufficiently corroborated, suggests a positive implication for manpower policy. If short-term manpower supply considerations actually constrain the extent and effectiveness of technological advance, an objective of long-term manpower supply policy should be to secure relaxation or removal of these constraints, thus facilitating the implementation of future more complex high-productivity systems. The most critical consideration here is the long lead-time (2-5 years or more) needed to educate and train individuals to the level ideally needed for routine operation and maintenance of highly advanced production processes. This implies that the planning horizon for a viable program should be at least ten years. We therefore propose that consideration should be given to the establishment of a federally-supported apprenticeship scheme for advanced production technology. A detailed discussion follows.

Training for Routine Production and Maintenance Roles in Advanced Production Systems

While some private organizations do operate successful long-term educational and training programs to meet their own projected manpower-supply needs, these seem to be geared principally to the requirements of equipment and system design and development; they do not as a rule produce highly skilled staff for long-term routine operation of advanced systems once designed, built and commissioned. Consequently there is a gap, due to manpower supply constraints, between the technical feasibility of new processes at the level of design concept and construction, and their operational viability. This gap could be closed by increasing the supply of highly qualified labor available for routine operation and maintenance functions as distinct from design and construction, which in turn would permit more advanced systems to be implemented on a fully operational basis. Put differently, we suggest that an active attempt should be made to raise the skills of the direct production work force to a level permitting fuller exploitation of advanced technology, and hence increasing the real wealth of the nation.

Outline Design of a Modernized Apprenticeship System

Considerations of educability, distribution of intelligence in the population, cultural background, and other factors outside the purview of this report suggest that since a viable program would aim to produce high-quality personnel who would nevertheless be willing to remain in production and routine maintenance roles for prolonged periods, effort should be concentrated on potential labor force entrants in the middle, rather than the upper, level of the spectrum of innate abilities. Following established precedent, the requisite education and training would therefore take the form of an apprenticeship. Opportunities of this type should be made available to potential labor force entrants who, though not highly able in the academic sense, are yet capable of grasping theories, concepts, and general principles having direct relevance to their future work as operators and maintenance personnel.

The knowledge content and work experience provided under the proposed new scheme should be markedly different from that found in present-day apprenticeship schemes. Our studies of advanced technologies indicate that computer technology (digital data-processing, programming and digital remote control), together with analog instrumentation and automatic control, are basic to all modern production and service systems, so this should form a major part of the core curriculum. However, their applications vary widely from industry to industry in response to specialized needs, so that no single generalized cross-industry curriculum would serve. Production and maintenance workers also obviously require specialized knowledge of plant, products, and processes specific to their own industry. Therefore the training should be differentiated by industry.

Recent studies of the contemporary apprenticeship system, such as that by Strauss*, suggest that while there is little immediate demand for apprentices, this is because existing schemes are largely tailored to older, often outdated, types of technology and skill and also indicate that

> "...our college-oriented school system seems not to be meeting the needs of a large part of our youth."**

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* Strauss, George, "Apprenticeship: An Evaluation of the Need" in A.M. Ross (ed.), Employment Policy and the Labor Market, University of California, Berkeley, 1965.

** op.cit., p. 332.

In our view a system newly structured and adapted to what can now be recognized as a dominantly computer-based pattern of modern production and service technology, would make a valuable contribution to the overall stability and growth of the economy.

We thus arrive at the concept of a modernized work/study program akin to the classical apprenticeship system, but focused on contemporary technology and providing potential for growth in the direction most likely to be taken by future technology. This would provide classroom instruction and practical experience with advanced equipment and methods, both continued in parallel over a long enough period to ensure a thorough practical and adequate theoretical grasp of contemporary technology in the specific industry for which the trainee is being prepared.

Proposals for Federal Action

Our specific proposal is that Federal and State authorities should actively support a certain number of middle-level students and other labor force entrants prepared to commit themselves to long-term technological training, and that they should initiate and sponsor the development of educational and training programs, structured broadly as an apprenticeship system and meeting the requirements outlined above.

Much of the groundwork for a viable program already exists. In many areas, especially where there is a high concentration of industry, there is a close relationship between management of advanced technological systems and local educational institutions. The latter could provide classroom and laboratory facilities, while their staff capabilities would be augmented (as is already the case in some places) by bringing in local managers and engineers. Ways and means of extending this pattern to less well-endowed localities should be explored, and here again there is room for Federal and State action.

In summary, we suggest that consideration should be given to government support for a modern technological training program of apprenticeship type, intended to train labor force entrants in modern computer-based production and control technology as applied in specific industries, with the long-run objective of providing a steady supply of highly qualified operating and maintenance personnel for new processes.

9.4 Full Employment Policy, Aggregate Demand and the "Labor-Static" Hypothesis

In the previous report we demonstrated that demand for labor was becoming increasingly inelastic with respect to demand for the product or service. This was done by projecting future manpower requirements for four processes studied (in banking and steel making). All four showed signs of entering, or having already entered, a phase of technological development we described as "laborstatic," in which the manpower required by a process or industry would remain constant, despite change in demand for the product within the economically plausible range. We considered this state to have been entered when increases in labor productivity, achieved by continuous small technical improvements, sufficed to offset normal increases in demand for product, permitting increased demand to be met with a constant labor force. It was suggested that this situation is associated with near-total elimination of direct human participation in the production process itself. An earlier discussion by Crossman cited aggregate data from selected industries as *prima facie* evidence for this hypothesis.[*]

Short and Long-Term Laborstaticity

On studying further technology types and examining aggregate production/employment statistics, we have subsequently found it necessary to draw a distinction between two types of laborstaticity, a short and a long-term form. The above description covers the long-term form, characterized by constancy of the 5 to 10 year average labor force for an industry or process. In the short-term form, while the long-term average labor force may show either an increasing or decreasing trend, employment fails to respond to fluctuations in demand over a shorter (1 to 3 year) period. The two types are not mutually exclusive, nor can a sharp boundary be drawn between them. Both are often, but not invariably, associated with advanced technology. The present discussion centers on the short-term form since it appears to have a more direct bearing on economic policy.

In the second sample of processes presented in this report, both short and long-term laborstaticity was encountered again, most markedly in electricity generation and oil refining. The sample also included one case (air separation) where the labor force was not only constant despite changes in demand, but also nearly non-existent. This appears to deserve recognition as a further distinct pattern of manpower demand (or non-demand) created by technological advance. Including the normal case of fully elastic labor demand, we therefore recognize three distinct basic types of technologically-created production/employment relationships, viz., labor-elastic, laborstatic, and zero-labor.

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[*] E.R.F.W. Crossman, Automation, *Skill and Manpower Predictions*, Seminar on Manpower Policy and Program, U.S. Department of Labor, Manpower Administration, 1966

Both the classical and neo-classical (Keynesian) approaches to full-employment policy appear to assume that the "normal" (labor-elastic) relationship holds, and that therefore employment is fully responsive to demand and can be readily controlled by way of fiscal and monetary instruments. But if the short- and/or long-term laborstatic condition comes to replace the labor-elastic condition over a sufficiently large area of the economy, there will be a marked decrease in the responsiveness of employment to short-run changes in demand, whether the latter are induced deliberately or by spontaneous economic forces. If and when this comes about, we must anticipate that certain hitherto reliable policy instruments will break down, and unanticipated difficulty will be encountered in stabilizing employment at desired near-full levels despite high levels of aggregate demand. On the positive side, however, a spreading laborstatic condition might be expected to reduce the severity of the business cycle* and largely remove the need for fast corrective action to stabilize demand. Current evidence examined below suggests that up to 40% of the labor force may already be employed in partially or wholly laborstatic organizations, so that discussion of such policy implications is far from a purely academic exercise.

The following section gives details of measurement methods, discusses the policy implications of this technologically-created change in the dynamic behavior of the economy labor market, and suggests a field for further study of manpower problems in relation to technology and general economic and business policy.

Types of Production/Employment Relationships; Definition of Laborstaticity

Despite numerous technical discussions of labor-input production functions contained in the literature, the quantitative impact of changing technology on the production/employment relationship seems hitherto to have attracted rather little interest among economists and policy analysts. Yet technology is certainly the major determinant of the link between output of production and demand for labor. Its changing status in given industries at different periods might be expected to induce economically significant changes in their dynamic response to market forces. Lacking a satisfactory literature reference, we now present the outline of a quantitative analysis to facilitate interpretation of our current data.

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*It is possible that the recent (since 1958-60) reduction in severity of cyclic fluctuations may have been at least partly due to this structural change in the economy.

Without going into undue technical detail, it seems reasonable to represent employment in a given industry or sector of the economy as a linear function of production:

$$E = aP + b \qquad (1)$$

where

E = aggregate employment in a process or industry in manhours per unit time.

P = aggregate production of that process or industry in product per unit time.

a = its marginal labor requirement in manhours per unit product.

b = its basal labor requirement in manhours per unit time.

This equation, the inverse of a production function, will validly model the behavior of a given industry or sector only (a) during some definite relatively short (< 10 years) period; and (b) within a moderate range of variation about a mean production-rate $\bar{P}$.

The values of the parameters $\underline{a}$ and $\underline{b}$ depend on several physical and structural factors, technology being prominent among them. In what follows we discuss effects due to technology, but we do not intend to imply that this is the only important influence. We proceed to define three basic and one transitional production/employment relationship created by advancing technology.

(i) Full labor-elasticity

In manufacturing and service technology of the classical type, where nearly all the operations performed require direct human manipulation or control, and relatively little labor is required to maintain plant and systems, the total marginal labor-requirement $\underline{a\bar{P}}$ will be much larger than the basal component $\underline{b}$. The marginal (incremental) labor demand per unit product $\Delta E/\Delta P$ is then equal to $\underline{a}$ and will also be nearly equal to the average labor demand per unit product $\bar{E}/\bar{P}$ (itself equal to $\underline{a}$). Hence, expressing the marginal elasticity in dimensionless form as a coefficient of relative elasticity ε , where

$$\varepsilon = \Delta E/\bar{E} \;/\; \Delta P/\bar{P} \,, \qquad (2)$$

we infer that, in the case of full elasticity,

$$\varepsilon (= a/a) = 1 \;,\; (a\bar{P} \gg b) \;. \qquad (3)$$

(ii) Full laborstaticity

The result of high-level mechanization, as seen in our case-studies, sometimes termed automation but better regarded as partial automation, is to diminish the fraction of labor devoted to direct manipulation and control of in-process material, and increase the fraction devoted to maintaining the plant as a whole and its component systems. While the work force may still be classified as "direct production labor," it actually has no immediate physical or mental involvement in production, and its continuous presence is not required to maintain output. Thus the parameter $\underline{a}$ is diminished and $\underline{b}$ increased. In the limiting case when the marginal component of employment $\underline{a}\bar{P}$ becomes much smaller than the basal component $\underline{b}$ we have the fully laborstatic case

$$\epsilon(= 0/b) = 0\ , \quad (a\bar{P} \ll b)\ . \tag{4}$$

The average labor requirement $\bar{E}$ is then equal to $\underline{b}$, and the actual (instantaneous) level of employment E is also equal to $\underline{b}$, and independent of product volume P .

(iii) Intermediate elasticity

At an intermediate stage, for instance when $\underline{a}\bar{P} = \underline{b}$ and therefore $\bar{E} = 2\underline{b}$, we have

$$\epsilon(= a \cdot b/a\ /\ 2b) = 0.5\ , \quad (a\bar{P} = b)\ . \tag{5}$$

Interpolating between these three cases we predict that the coefficient of relative labor elasticity ϵ should diminish from unity through fractional values to zero as technology advances toward full mechanization.

(iv) The zero-labor case

Full automation (in the strict sense) implies that indirect process-related work functions are also taken over by machines. In the ultimate case, exemplified by the new air separation process described in Chapter 6, both $\underline{a}$ and $\underline{b}$ have very small values, and the coefficient of elasticity cannot then be defined. This case is distinguished from that of partial automation (full laborstaticity) by a very low level of mean employment $\bar{E}$, and we have termed it the zero-labor condition, where

$$\epsilon(= 0/0) \text{ is undefined}\ , \quad (\underline{a} = \underline{b} = 0)\ . \tag{6}$$

Technology and Diminution of Labor-Elasticity

The progressive impact of technology advance on the elasticity of labor requirements in the sample of processes studied is summarized in Table 9.1. It will be seen that while in three cases out of nine there was no change, in five cases the production/employment relationship became more laborstatic, and in one it went from laborstatic to zero-labor. As demonstrated by our data, the average trend with advancing technology is therefore for processes to progress from elastic to laborstatic to zero-labor conditions.

Further direct analysis of aggregate production/employment statistics for these and other whole industries[*] corroborates the above conclusion based on theoretical and case-study approaches. We have examined production and employment series for various industries as summarized in a recent report of the Bureau of Labor Statistics[**], for evidence of laborstaticity in the period 1957-1963. high and low production years were selected for each industry and an estimate $\underline{\hat{\varepsilon}}$ of the dimensionless coefficient of labor-elasticity ε was formed using Equation (2) in the discrete form

$$\underline{\hat{\varepsilon}} = \frac{(E_1 - E_2)}{(P_1 - P_2)} \cdot \frac{(P_1 + P_2)}{(E_1 + E_2)} \qquad (7)$$

where

E_1 , E_2 = employment in two selected years

P_1 , P_2 = production in the same two years .

As shown above, this index would ideally take the value 1 for a fully labor-elastic industry, 0 for a fully laborstatic one, and intermediate values in transitional cases. In the zero-labor case it will be undefined and in addition $\bar{E}$ would then be very small, but this case is not encountered in aggregate statistics. Results are presented in Table 9.2 and Figure 9.1.

Due to sampling error, a few values of $\underline{\hat{\varepsilon}}$ greater than 1 and less than 0 were encountered, but in general the results agreed with our expectations based on descriptions of the technology of the industries in question as given in the report cited. The overall distribution of laborstaticity was as follows (see Table 9.2). Out of a total labor force of 13.5 million employed

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[*] presented in Appendix H.

[**] Technological Trends in Major American Industries, Bulletin #1474, U.S. Department of Labor, Bureau of Labor Statistics, 1966.

TABLE 9.1

Production/Employment Relationship	Technological Status	Work-Force Participation in Production	Constants		Examples
			a , b	ε	
Labor-Elastic ("Normal")	Partial mechanization, no automation. Direct human participation.	Proportional to Demand ($E \propto P$)	$a\bar{P} \gg b$	1	Machine-aided manual passenger reservations Machine-aided manual check-processing Conventional and numerically controlled machining Batch annealing Batch steel sheet coating
(Transitional)			$a\bar{P} \approx b$	≈ 0.5	Part computerized passenger reservations Mechanized check-processing Power generation - non-centralized manual control
Laborstatic	Full mechanization and partial automation. Little or no direct human participation. Substantial indirect human participation.	Constant (Independent of Demand) (E constant)	$a\bar{P} \ll b$	0	Continuous steel strip annealing Continuous steel strip coating Power-generation - centralized manual control Oil-cracking - centralized manual control Air separation - centralized manual control Power generation - part-computerized control Oil-cracking - part-computerized control
(Transitional)			$a\bar{P} \ll b$ b small	0 , $\bar{E}$ small	
Zero-Labor	Full mechanization and automation. No direct, and little or no indirect human participation.	Zero ($E = 0$)	$a = b = 0$	undefined $\bar{E} = 0$	Fully comp[illegible]controlled air separation plant

TABLE 9.2: EMPLOYMENT AND LABOR-ELASTICITY OF VARIOUS INDUSTRIES AND SERVICE GROUPINGS, U.S.A., 1957-1963

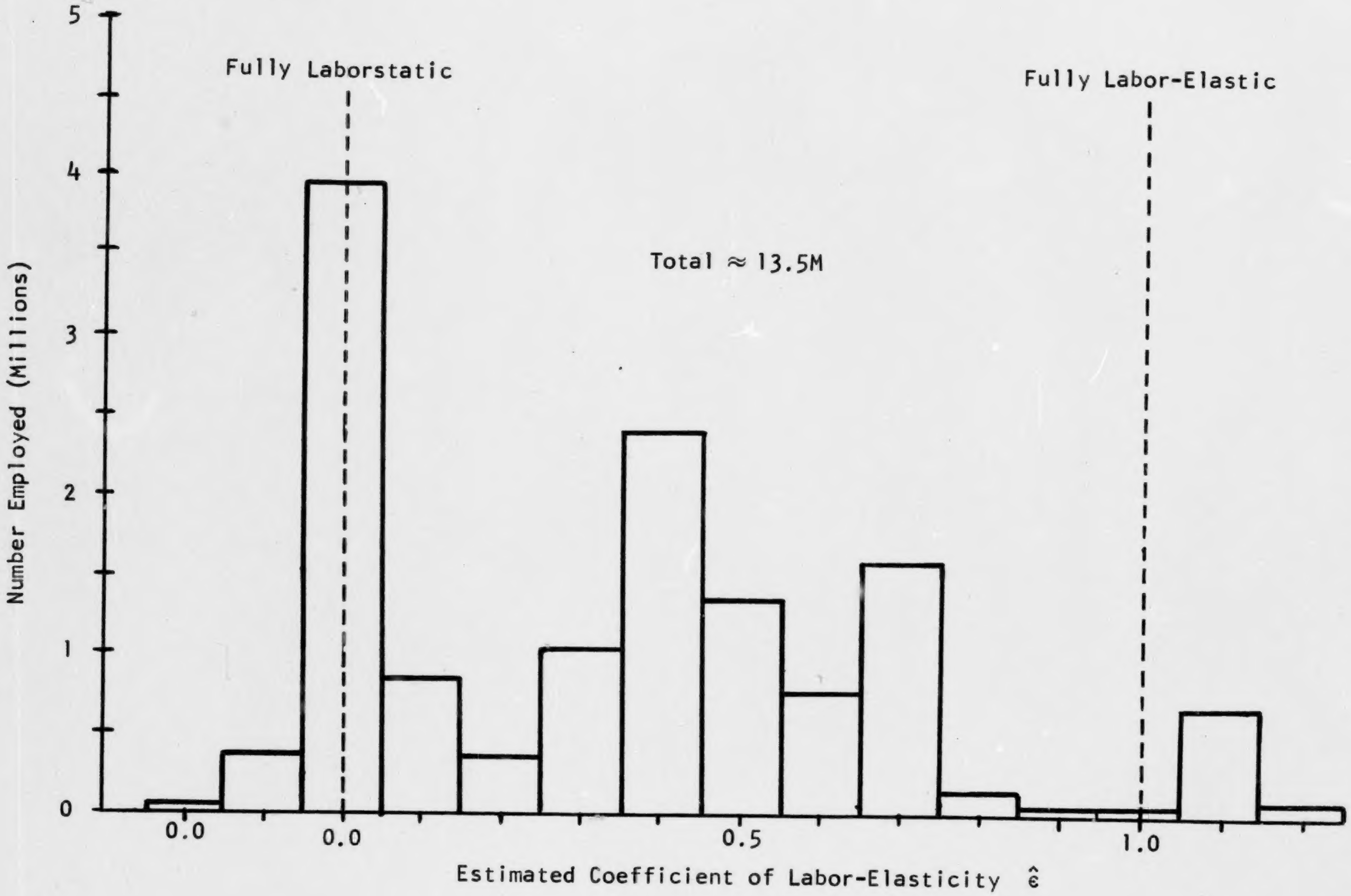
	Average Employment (Thousands)	
Fully Labor-Elastic (ε > 0.75)		
Copper Ore Mining (SIC 102)	28	
Concrete, Gypsum and Plastic Products (SIC 327)	150	
Electrical Machinery, Equipment and Supplies (SIC 36)	1,325	
Motor Vehicles and Equipment (SIC 371)	675	
		2,178
High-Elasticity Intermediate (0.74 ≥ ε > 0.50)		
Bituminous Coal Mining (SIC 12)	205	
Crude Petroleum and Natural Gas (SIC 13)	330	
Lumber and Wood Products (except Furniture) (SIC 24)	650	
Iron and Steel Foundries (SIC 332, 336)	202	
Non-Ferrous Foundries (SIC 332, 336)	64	
Primary Aluminum (SIC 3334, 3352)	67	
Air Transportation (SIC 452)	175	
Banking (SIC 60)	715	
		2,408
Low-Elasticity Intermediate (0.49 ≥ ε > 0.25)		
Apparel (SIC 23)	1,203	
Printing and Publishing (SIC 27)	925	
Synthetic Materials and Plastic Products (SIC 282, 3079)	165	
Tires and Inner Tubes (SIC 301)	90	
Footwear (except Rubber) (SIC 314)	230	
Motor Freight (SIC 42)	810	
		3,423
Laborstatic (ε ≤ 0.24)		
Hydraulic Cement (SIC 324)	42	
Iron and Steel Industry (SIC 331)	600	
Instruments and Related Products (SIC 38)	335	
Meat Products (SIC 201)	320	
Dairy Products (SIC 202)	328	
Flour and Other Grain Mill Products (SIC 2041)	25	
Bakery Products (SIC 2051, 2052)	300	
Malt Liquors (SIC 2082)	70	
Tobacco Products (SIC 211, 212, 213)	40	
Cigar Industry (SIC 212)	25	
Textile Mill Products (SIC 22)	863	
Pulp, Paper and Board (SIC 261, 262, 263, 266)	230	
Petroleum Refining (SIC 291)	120	
Railroads (SIC 401)	700	
Water Transportation (SIC 44)	230	
Telephone Communication (SIC 481)	680	
Electric Power and Gas (SIC 491, 492, 493)	570	
		5,478
Groupings for Which ε Could Not Be Found		
Contract Construction (SIC 15, 16, 17)	2,900	
Furniture and Fixtures (SIC 25)	370	
Glass Containers (SIC 3221)	60	
Aerospace (SIC 372, 192)	780	
Wholesale and Retail Trade (SIC 50, 52-59)	11,800	
Insurance Carriers (SIC 63)	370	
Federal Government (SIC 91)	2,300	
		19,080

Summary

	Employment	Percent of Measurable Total		Percent of Overall Total
Elastic	2,178	16.0%	34%	6.7%
High-Elasticity Intermediate	2,408	18.0%		7.4%
Low-Elasticity Intermediate	3,423	25.0%	66%	10.5%
Laborstatic	5,478	41.0%		16.8%
Total Measurable	13,487	100.0%		41.4%
Not Measurable	19,080			58.6%
Overall Total	35,567			100.0%

FIGURE 9.2: DISTRIBUTION OF PRODUCTION/EMPLOYMENT ELASTICITY OVER PART OF THE EMPLOYED LABOR-FORCE 1957-1963

(The coefficient plotted is $\hat{\varepsilon}$ as defined in the text.)



in industries for which $\underline{\hat{\varepsilon}}$ could be estimated[*] 41% of the total was found to be employed in laborstatic industries ($\underline{\hat{\varepsilon}} < 0.25$), 43% in transitional ones ($0.25 < \underline{\hat{\varepsilon}} < 0.75$), while only 16% was in fully labor-elastic industry ($\underline{\hat{\varepsilon}} > 0.75$). While these estimates cannot be taken as definitive without more elaborate statistical treatment, and though they cover only a fraction of the total labor force, they certainly point to the existence of a sizeable laborstatic sector in the contemporary economy.

The association of laborstaticity with advanced technology was confirmed on a small-sample basis by the correct identification of several of our sample processes with industries having corresponding aggregate employment/output relationships (see Table 9.3).

Implications of Laborstaticity for Full-Employment Policy

The main implications of the above results for manpower policy derive from the selective (nonuniform) incidence of laborstaticity by type of industry and service. Generally speaking basic nondurable consumer goods and bulk raw-material manufacturing industries, together with highly organized transportation and communication services, appear to have become, or to be in the process of becoming, laborstatic, while capital goods and consumer-durable industries remain elastic. Mining and other natural resources exploiting industries, such as Lumber and Wood Products, also retain some elasticity. There are certain anomalous cases, such as the Instrument industry which appears to be almost laborstatic but probably for other than directly technological reasons; in this case we surmise that the condition is probably due to the industry's manpower policy, viz., the deliberate preservation of skilled research, design and development teams despite fluctuating levels of demand.

This uneven distribution of laborstaticity across industries indicates a need to consider the precise pattern, as well as the absolute level of demand, created by aggregate economic policies aimed at promoting and/or maintaining full employment. If for instance a given increment of demand were created in the market for consumer non-durables and for mass services, this would seem likely to cause a much smaller increase in overall employment than a similar increment in the capital goods and/or consumer-durables market. The same effect may also be expected to operate in the reverse direction, so that a decline in demand for the former goods should not reduce employment as much as a similar fall-off in the latter area. The "multiplier" is also affected. Since any increase in (primary) demand for products of labor-elastic industries will result in some (secondary) demand directed towards laborstatic industries, we might also expect that the multiplier effect will be attenuated by the trend towards laborstaticity. Thus no matter where a given change in aggregate demand has its primary impact, the effect on overall employment should be less than previously. We infer that the net effect of laborstaticity is to stabilize the economy at a given level of employment. This is acceptable if the level in question is adequately high. If not, laborstaticity may make it significantly more difficult to remedy the situation by the use of orthodox fiscal and monetary policies. In the latter case, the present analysis points to the capital goods and consumer durables sectors as providing the best employment response to a given increment of aggregate demand.

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[*] Output data were missing or considered invalid in the remainder of cases with total employment of 19 million.

The present[*] manpower situation seems particularly vulnerable to employment problems created by switching demand from laborelastic to laborstatic areas of the economy. The critical increment of aggregate demand needed to approach full employment was apparently generated in the period 1964-1966 by increased defense spending for military procurement, overseas military aid, and the space program. As illustrated by Figure 9.2, showing annual employment by sector 1947-67, there was a marked stepwise increase in employment in manufacturing industry at this time, presumably associated with the increase in demand for military and space equipment. The industries concerned almost certainly use laborelastic technology. While we cannot currently present adequate data to prove the point, it therefore seems likely that much recently generated manpower demand is concentrated in labor-elastic rather than laborstatic industries and organizations.

In the absence of deliberate preventive policies, any cutback in this particular component of aggregate demand, such as will be caused by ending the Vietnam involvement and/or phasing out the space program, may be expected to cause an immediate reduction in aggregate employment, which would not occur were the demand in question concentrated in laborstatic sectors. In order to maintain the employment status quo, it will be necessary for the resulting deficit in aggregate demand, produced by the postulated cutbacks, to be made good by creating fresh demand in equally laborelastic sectors of the economy.

Our present data indicate that the main manufacturing industries in this category are consumer durables and capital goods producers. The latter market is already active and may well be incapable of the necessary expansion within limits of potential private investment spending, while the former would require a relatively large further increase in private consumption to absorb labor in the amount likely to become available. Therefore it seems advisable to give urgent attention to examining possibilities of generating the required demand in other labor-elastic sectors. Analysis of

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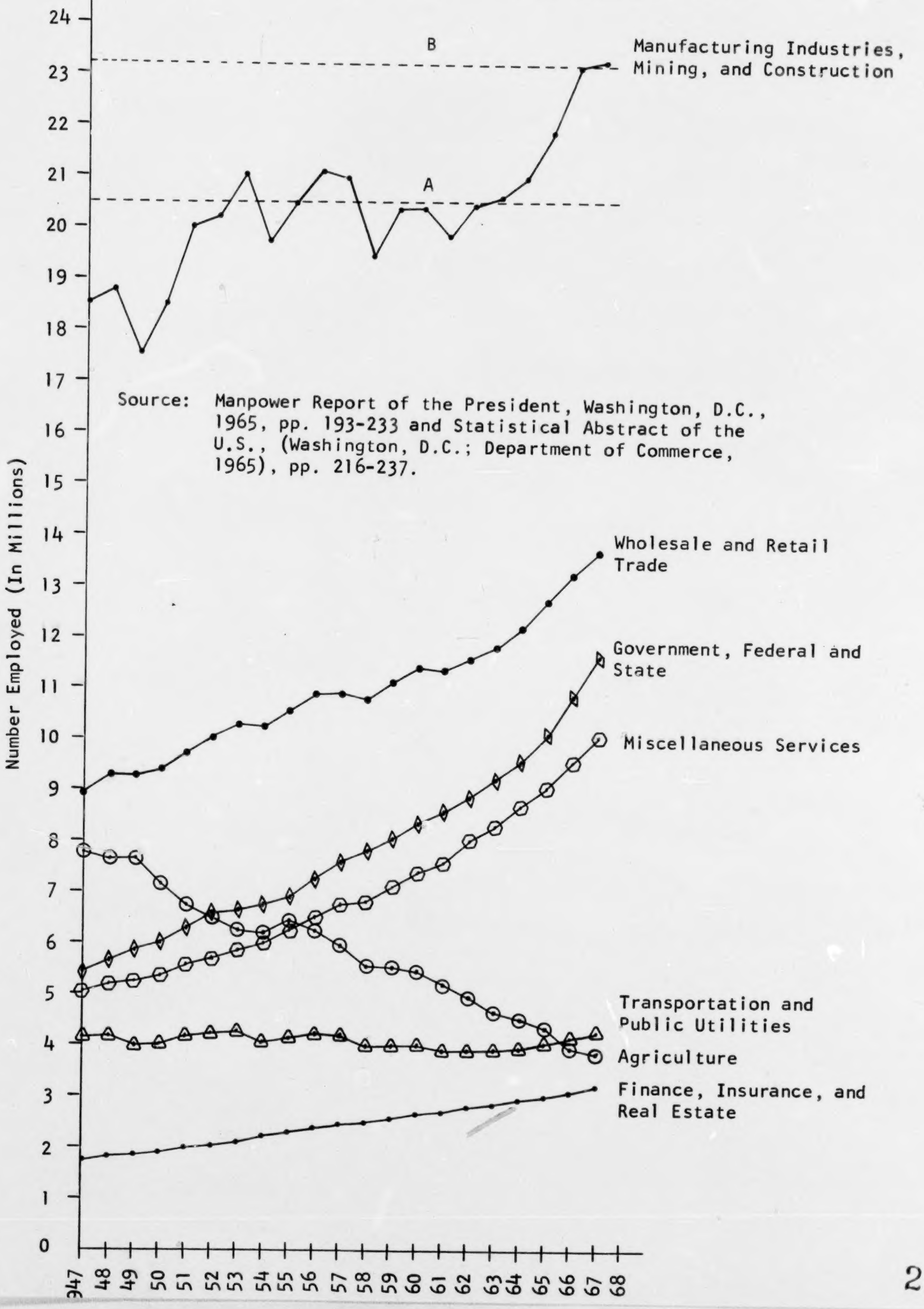
[*] early 1969.

TABLE 9.3: AGGREGATE LABOR-ELASTICITY (1957-63) OF INDUSTRIES CONTAINING SAMPLE PROCESSES

Process	Industry	Estimate of Elasticity	Classified on Aggregate Statistical Basis
Check-Processing and Account Posting	Banking	0.52	Intermediate
Coating Annealing	Steel	-0.25	Laborstatic
Machining Complex Parts	Aerospace	N/A	(Probably Labor-Elastic)
Electricity Generation	Electricity with Gas and Power	≈ 0	Laborstatic
Catalytic Cracking	Oil Refining	≈ 0	Laborstatic
Air-Separation	Chemical	N/A	(Probably Laborstatic)

FIGURE 9.2: LABOR FORCE AND EMPLOYMENT BY INDUSTRY



Source: Manpower Report of the President, Washington, D.C., 1965, pp. 193-233 and Statistical Abstract of the U.S., (Washington, D.C.; Department of Commerce, 1965), pp. 216-237.

the role of manpower and technology in various alternative sectors suggests that the most plausible candidates are health care, education, social welfare, and other low-technology personal services. However, as is well known, these occupations impose minimum standards well above the qualifications possessed by the segment of the labor force likely to be released by the cutbacks, so this option in turn raises a structural problem in maintaining full employment.

Need for Further Data on Labor-Elasticity and Laborstaticity

We do not consider it appropriate to analyze further specific full-employment policy options that might be selected in response to projected defense and space cutbacks in the present report, and the main purpose of carrying the discussion thus far has been to indicate the necessity of taking the onset of laborstaticity and loss of labor-elasticity into account when examining proposed adjustments and projecting the likely employment impact of changes in demand distribution.

It should be pointed out that while related to it, laborstaticity is by no means the same thing as high average productivity, and we are not simply reiterating the often propounded and eminently false proposition that increases in average productivity automatically cause unemployment. We claim instead that marginal productivity has (in some industries) risen much faster than average productivity, reaching a value which is effectively infinite when short-period fluctuations are considered. This affects short-run adjustment mechanisms rather than creating a long-run employment deficit.

There is an immediate need for better-controlled and more fully documented analyses of these short-run production/employment relationships in various industries and services. Labor-elasticity (with respect to demand and/or production) should be examined on a response-lag basis to obtain insight into the time-dynamics of the process on a more adequately quantitative basis than we have been able to develop in the present contribution. This could readily be done using available aggregate time-series with modern statistical and computational tools, particularly spectral methods*.

Interpretations of the results in terms of changing industrial and service technology, while not essential to permit use of elasticity data for purposes of manpower planning, forecasting, and policy formation, would contribute greatly to understanding of the underlying trends and would permit more confident extrapolation of current trends into the remoter future, should this be deemed desirable. Quite apart from statistical study, it would also seem profitable to conduct further sample surveys of the impact of technology and organization on the production/employment relationship on a case-study basis, to provide early warning of future changes, particularly in the less highly organized sectors of the economy.

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*Such as those developed by G.W. Granger and W. Hatanaka, Spectral Analysis of Economic Timeseries. Princeton, 1964.

In summary, we conclude from our case-study data, together with examination of aggregate production/employment series for the relevant and other industries, that technological advances displacing labor from direct production roles in many types of manufacturing and service processes tend to create, and to a large extent already have created, a "laborstatic" sector of the economy. This is characterized primarily by short-term, but also sometimes by long-term, unresponsiveness of employment to changing demand for the product or service. To date laborstaticity is mainly characteristic of industries producing consumer nondurables, bulk raw materials, and power; and those providing mass services, such as transportation and communication. This development renders it essential to consider the specific distribution of projected changes in aggregate demand, whether produced by market forces or actively generated by fiscal or monetary policy; and to be highly selective in formulating policies aimed at the maintenance of full employment. Considerably more complete analysis of existing data, and investigation of underlying technological and other factors causing laborstaticity, is required to permit confident inference as to the manpower consequences of specific policy options affecting aggregate demand.

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APPENDIX A

INDIRECT LABOR SKILL REQUIREMENTS FOR CHECK PROCESSING AND ACCOUNT POSTING IN A MULTI-BRANCH BANK

1. SELECTION, TRAINING, AND CLASSIFICATION OF MAINTENANCE PERSONNEL

Selection, training, and classification procedures for bank mechanics are quite different from those used for other employees of Firm A. This is mainly due to there being an obvious limit to the potential advancement of a mechanically skilled person in a bank where the primary skills relate to financial and accounting matters.

Applicants for jobs in the Mechanical Department are selected partly on the basis of a formal paper and pencil test. Successful applicants are classified as Trainee Mechanics for a maximum period of two years. The length of the actual training period, which includes study of instruction books, is determined by the supervisor and is usually less than the maximum. After the trainee has become familiar with either business machines or typewriters and miscellaneous equipment, he is advanced to a Mechanic position.

As regards job evaluation, Bank A's plan is designed for the usual kind of banking jobs and is not suitable for evaluating Mechanical Department personnel. There is no alternative scheme, rates of pay being set by reference to comparable jobs elsewhere in industry.

The Computer Manufacturer's Field Representatives are expected to have a high school education and to have undergone electronics training in a military or private school prior to engagement; the manufacturer provides an intensive six month training course which includes both class and on-the-job work. Field Representatives are classified into six grades, the length and amount of experience being the prime determinants of job grade assignment. Of the four Representatives at the EDP Center studied, two were in the lower grade (1-2 years experience) and two in the highest grade (about 12 years experience).

2. METHOD OF DERIVING MANHOUR INPUTS OF MAINTENANCE PERSONNEL

Unlike the computer manufacturer's Field Representatives who are permanently assigned to the bank's EDP installations, the bank's own mechanics pay flying visits to individual branch offices from localities central to one of several areas in the state.

Derivation of manhours for the Field Representatives was a simple matter of ascertaining the number of Representatives at the EDP Center where they work on an 8-hour shift basis.

A somewhat more involved procedure was necessary for determining the manhours of the bank's mechanics. The main source of data for this are job cards on which each mechanic enters the following information for each job: locations of branch office where repair was made, travel time to and from branch or EDP Center, time spent making repair, type of machine repaired, type of maintenance performed (preventative, emergency, overhaul).

Manhours for supervision were determined by direct observation and discussions with management.

3. DETAILED BREAKDOWN OF MAINTENANCE REQUIREMENTS

Table A-1 on the following page is a detailed breakdown of the labor requirements for the manual technology level (TL1) and the computerized technology level (TL2). In addition to the EDP-linked branch (BM) used as a data base for both direct and indirect labor several other EDP attached branches were examined and compared. These are designated as DW, HV, and UW. All labor at branch offices consists of the bank's own mechanics. The bank's Mechanical section personnel and the manufacturer's Field Representative, both of whom are required at an EDP Center, are listed separately.

The yearly manhour requirements were determined by the methodology explained in the preceding section. The manhours per 1000 item data, shown in the right half of the table, were derived by applying the manhour-per-year data to the volumes in the bottom row.

TABLE A-1: DETAILED BREAKDOWN OF CHECK PROCESSING MAINTENANCE MANHOURS

	TL1 Manhours Per Year	TL2 - Manhours Per Year					
		EDP Attached Branches				EDP Center	
	T	DW	HV	UW	BM	Mech.	Comp.
Total Maintenance	88.6	70.3	55.5	35.0	247.8	101.8	8320.0
Preventative	37.8	33.5	26.0	18.0	155.8	37.0	*
Unscheduled	10.8	36.8	29.5	17.0	92.0	64.8	*
Overhaul	40.0	0.0	0.0	0.0	0.0	0.0	*
Travel	18.6	11.0	7.5	6.3	35.0	30.0	0.0
Volume (1000 Items/Year)	480	718.2	540.3	1165.5	3120.0	91000.0	

	TL1 Manhours Per 1000 Items	TL2 - Manhours Per 1000 Items					
		EDP Attached Branches				EDP Center	
	T	DW	HV	UW	BM	Mech.	Comp.
Total Maintenance	0.18	0.10	0.10	0.03	0.08	0.001	0.09
Preventative	0.08	0.05	0.05	0.02	0.05	0.0004	*
Unscheduled	0.02	0.05	0.05	0.01	0.03	0.0007	*
Overhaul	0.08	0.00	0.00	0.00	0.00	0.0000	*
Travel	0.04	0.02	0.01	0.01	0.01	0.0003	0.00

*Unavailable

4. RAW DATA USED FOR DETERMINING MANHOUR AND SKILL REQUIREMENTS

These data are tabulated under the title of each system or subsystem, with the volume of product processed in parentheses. The following notes explain the meaning of each column in the tables.

Job Code:	The codes are internal codes, assigned to each job to facilitate cross-referencing. The letter identifies the firm, the attached figure identifies technology and the figure separated by a dash, the job.
Job D.O.T. Number:	These six digit numbers are taken from the 1965 edition of the Dictionary of Occupational Titles. The matching of D.O.T. Number and job was done by the researchers on the basis of job description and their own knowledge of the job.
Job Title:	Official titles assigned to the jobs by the firm.
Skill Level:	Total skill factor points derived from the job evaluation scheme operative within the firm.
Manhours:	Determined by use of methodology presented in Section 2 of this Appendix.
Volumes:	Figures are: A1 - average of 5 months' recorded volume. A2 (EDP-linked Branch)- average of 12 months' volume. A2 (EDP Center) - average of several days typical volume extracted by manager from records.

MAINTENANCE

A1 HAND PROCESSING

Non-linked Branch (Volume: 480,000 Items per Year)

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Year
A1-1m	633.281	Mechanic(Typewriter or Misc. Equip.) - A	156	5.00
A1-2m	633.281	Mechanic(Business Machines) - E	177	81.75

A2 COMPUTERIZED PROCESSING

E.D.P.-linked Branch (Volume: 3,120,000 Items per Year)

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Year
A2-1m	633.281	Mechanic(Typewriter & Misc. Equip.) - A	156	18.00
A2-3m	633.281	Mechanic(Business Machines) - E	177	231.50

Electronic Data Processing Center (Volume: 91,000,000 Items per Year)

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Year
A2-2m	633.281	Mechanic(Typewriter & Misc. Equip.) - A	156	4.75
A2-4m	633.281	Mechanic(Business Machines) - E	177	101.75
A2-5m	828.281	Field Representative I	177	2080.00
A2-6m	828.281	Field Representative I	214	2080.00
A2-7m	829.281	Field Representative VI	469	4160.00

SUPERVISION

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Week
A1 HAND PROCESSING				
Non-linked Branch (Volume: 9,230 Items per Week)				
A1-1s	186.168	Chief Clerk "B"	187	40
A2 COMPUTERIZED PROCESSING				
E.D.P.-linked Branch (Volume: 60,000 Items per Week)				
A2-1s	186.168	Assistant Operations Officer	177	48
A2-4s	186.168	Operations Officer	258	42
Electronic Data Processing Center (Volume: 1,750,000 Items per Week)				
A2-2s	169.168	Assistant Manager (Swing Shift)	243	40
A2-3s	169.168	Assistant Manager (Night Shift)	258	40
A2-5s	169.168	Manager	358	40

APPENDIX B

INDIRECT LABOR SKILL REQUIREMENTS IN BOX AND CONTINUOUS ANNEALING

1. PRODUCTION PLANNING

Description of Order Processing System

The activities and procedures involved in processing an order for sheets or coils of finished steel include five main stages:

1) Order Entry: for each new order, determination is made whether or not the steel specifications can be met with the existing technology. If the steel can be produced, the order is accepted and an anticipated delivery date is relayed to the customer. The particular raw steel to be used and the sequence of processes it will undergo are determined.
2) Steel Providing: If the required raw steel is not in inventory, it is requisitioned from the Hot Mill source and subsequently transported to the plant where it is placed in inventory. Records are initiated to identify the order to which the steel is to be applied.
3) Production Scheduling: The raw steel is scheduled through the mill by specifying when it will be produced. Tests are taken from each process utilized to ensure quality.
4) Warehousing: The finished steel is received and placed in designated locations in the warehouse.
5) Shipping: Dispatching of the coils scheduled and controlled. Customers are billed for the product.

2. MAINTENANCE

a. Sources of Data and Treatment

On every shift a member of the assigned maintenance crew logs his time on a job card. On it he records the production lines serviced during the shift and the number of hours worked on each of these lines as well as his badge number. Each member of the central maintenance crew also logs his time on a job card. However, all central maintenance work is requisitioned through job orders, so that job order numbers and hours worked on each during the shift are recorded on the job cards (rather than production lines) along with the employee's badge number.

Job cards, however, were but two of the five sources of data which were drawn upon for the construction of skill profiles consistent with those for direct labor*:

a) The numbers of all job orders relating to each of the annealing lines (1)

b) Job cards for all assigned-maintenance activities (2)

c) Job cards for central maintenance job orders (3)

d) The craft at which each person is employed (4)

e) The skill ratings associated with each craft, derived from established job evaluations (5)

The information from two of these sources (a) and (d), is maintained by the firm on magnetic tape and was subsequently converted to IBM cards. The information for the others was transcribed from thousands of job cards, and punch coded onto IBM cards. A computer program was written to make successive comparisons of data from each source to arrive at the hours spent by each maintenance skill-level on each of the annealing lines. The comparisons made are shown by the arrows in Figure B-1 for assigned maintenance. Information required for skill profiles is circled.

After all records had been processed by the computer, all hours spent on each annealing line were identified by the skill of the employee who contributed them. A similar procedure was followed for central maintenance, as can be seen from Figure B-2.

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*Digits in parentheses refer to diagrams in Figs. B-1 , B-2 .

FIGURE B-1: ASSIGNED MAINTENANCE DATA SOURCE INTEGRATION

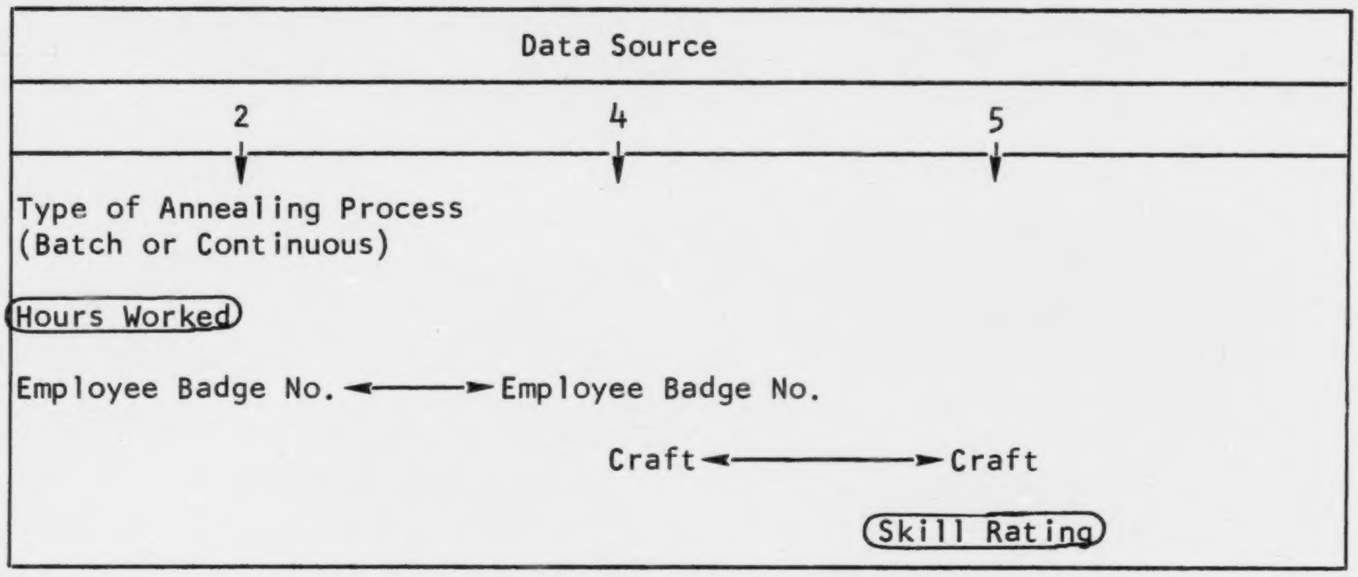
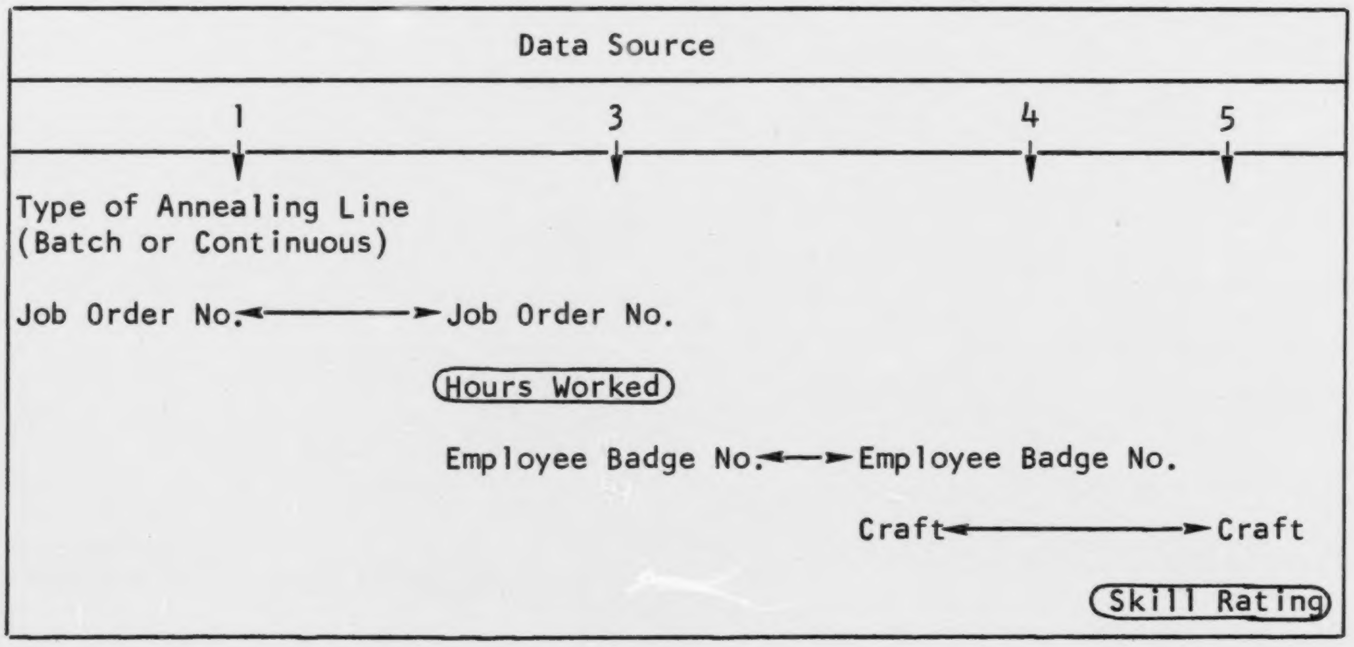

Data Source
2
4
5
Type of Annealing Process
(Batch or Continuous)
Hours Worked
Employee Badge No.
Employee Badge No.
Craft
Craft
Skill Rating

FIGURE B-2: CENTRAL MAINTENANCE DATA SOURCE INTEGRATION


Data Source
1
3
4
5
Type of Annealing Line
(Batch or Continuous)
Job Order No.
Job Order No.
Hours Worked
Employee Badge No.
Employee Badge No.
Craft
Craft
Skill Rating

b. Method of Deriving Skill Level Values from Steel Industry Job Evaluation Scheme

The identical job evaluation plan is used for both maintenance crafts and direct labor, so that a combined skill profile can readily be constructed.

Agreement on a common job evaluation scheme was reached between the steel industry and the United Steelworkers during the war years and all jobs on all processes throughout the industry have since been assessed on the basis of twelve factors:

PRE-EMPLOYMENT TRAINING
EMPLOYMENT TRAINING AND EXPERIENCE
MENTAL SKILL
MANUAL SKILL
Responsibility for Material
Responsibility for Tools and Equipment
Responsibility for Operations
Responsibility for Safety of Others
Mental Effort
Physical Effort
Surroundings
Hazards

The first four factors were used to derive skill "scores" for all jobs on the annealing processes at both technological levels.

Pre-Employment Training is defined as "the mentality required to absorb training and exercise judgement for the satisfactory performance of the job." Three discrete values are possible within the range 0-1.0.

Employment Training and Experience -- definition: "Time required to learn how to do the job satisfactorily. This includes time spent on directly related work and on the specified jobs." Number of discrete values possible: 9, in the range 0-4.0.

Mental Skill -- definition: "Mental ability, job knowledge, judgement, and ingenuity required to visualize, reason through, and plan the details of a job without recourse to supervision." Number of discrete values possible: 6, in the range 0-3.5.

Manual Skill is defined as "physical or muscular ability and dexterity required in performing a given job including the use of tools, machines and equipment." Number of discrete values possible: 5, in the range 0-2.0.

The range for the employment training and experience factor is greatest, followed by the mental skill range. These two factors thus carry most weight when the points are added for any given jobs to yield the total skill "score."

The job classes for all standard jobs, which are those acquired after completion of all training, are determined by application of the job evaluation plan. Non-standard jobs, that is jobs at the apprentice level, intermediate, and starting levels (see discussion of training in next section) are not included under the job evaluation plan by the firm. By agreement with the union the classification and wages for these jobs are established on the basis of the corresponding standard job. For example, the Machinist-Starting position and the Machinist-Intermediate are set at 4 and 2 job grades respectively below the Machinist-Standard job. The schedule of grades for the Machinist Apprentice is set up to reflect the number of training periods completed.

Since the firm does not assign points to the non-standard job, a scheme has been devised which assigns points by applying a percentage to the points given to factors 2, 3, and 4 for the corresponding standard job. The percentage depends on the level of the non-standard job -- that is, the degree to which a person in that job has progressed toward acquiring the standard classification. The percentage is not applied to the first factor, pre-employment training, which is concerned with the mentality to learn. This is a prerequisite possessed by both the standard and non-standard job and is required for entry into the apprenticeship program.

The following is an example of the determination of skill points for the Welder-Intermediate job.

Total skill points for factors 2, 3, 4-- Welder Standard	6.1
Adjustment percentage	0.89
Total skill points for factors 2, 3, 4-- Welder Intermediate	5.4
Skill points for factor 1--Welder Standard	1.0
Skill points assigned to Welder Intermediate	6.4

The adjustment percentage is determined from the promotional sequence of jobs leading to the Standard job. Since 9 steps comprise the progression which consists of 6 apprentice training periods of 6 months each, a 6 month period as Welder-Starter, a 6 month period as Welder-Intermediate, and the Standard position, the Intermediate level represents an 8/9 (89%) completion of the requirements for the Standard job.

As a result of number of periods in the training program, the Starter period, and the Intermediate period, each 6 month period of the progression which has been completed accounts for the following percentage for each craft:

Painter	14.3%
Pipefitter	11.1%
Welder	11.1%
Rigger	11.1%
Millwright	10.0%
Machinist	9.1%
Electrician Wireman	9.1%
Electronic Repairman	9.1%
Instrument Repairman	9.1%

c. Training Data

By agreement with the union, the company set up a formal apprenticeship program for most trade and craft jobs. The apprenticeship training program consists of a series of 6 month training periods combining both classroom training and on-the-job experience. The number of training periods depends on the craft involved. The crafts performing maintenance on the annealing lines and their respective number of apprenticeship training periods are:

Painter	4
Pipefitter	6
Welder	6
Rigger	6
Millwright	7
Machinist	8
Electrician-Wireman	8
Electronic Repairman	8
Instrument Repairman	8

For all craft jobs the promotional sequence leading to the standard job consists of the apprenticeship program followed by a 6 month on-the-job training period as a Starter and a 6 month on-the-job training period at the Intermediate level. Thus the training period required to become, for instance, an Instrument Repairman, is 5 years.

d. Skill Profiles for Central and Assigned Maintenance

Tables B-1 and B-2 and Figures B-3 and B-4 show the manhour-per-10-ton contribution of each skill level.

TABLE B-1: ASSIGNED MAINTENANCE SKILL DISTRIBUTIONS FOR BATCH (TL1) AND CONTINUOUS (TL2) ANNEALING PROCESSES

Organization: Firm C

Process: Annealing Product Unit: 10 Tons

Technology (Level 1): Box Annealing

Technology (Level 2): Continuous Annealing

Source of Data: Company Records

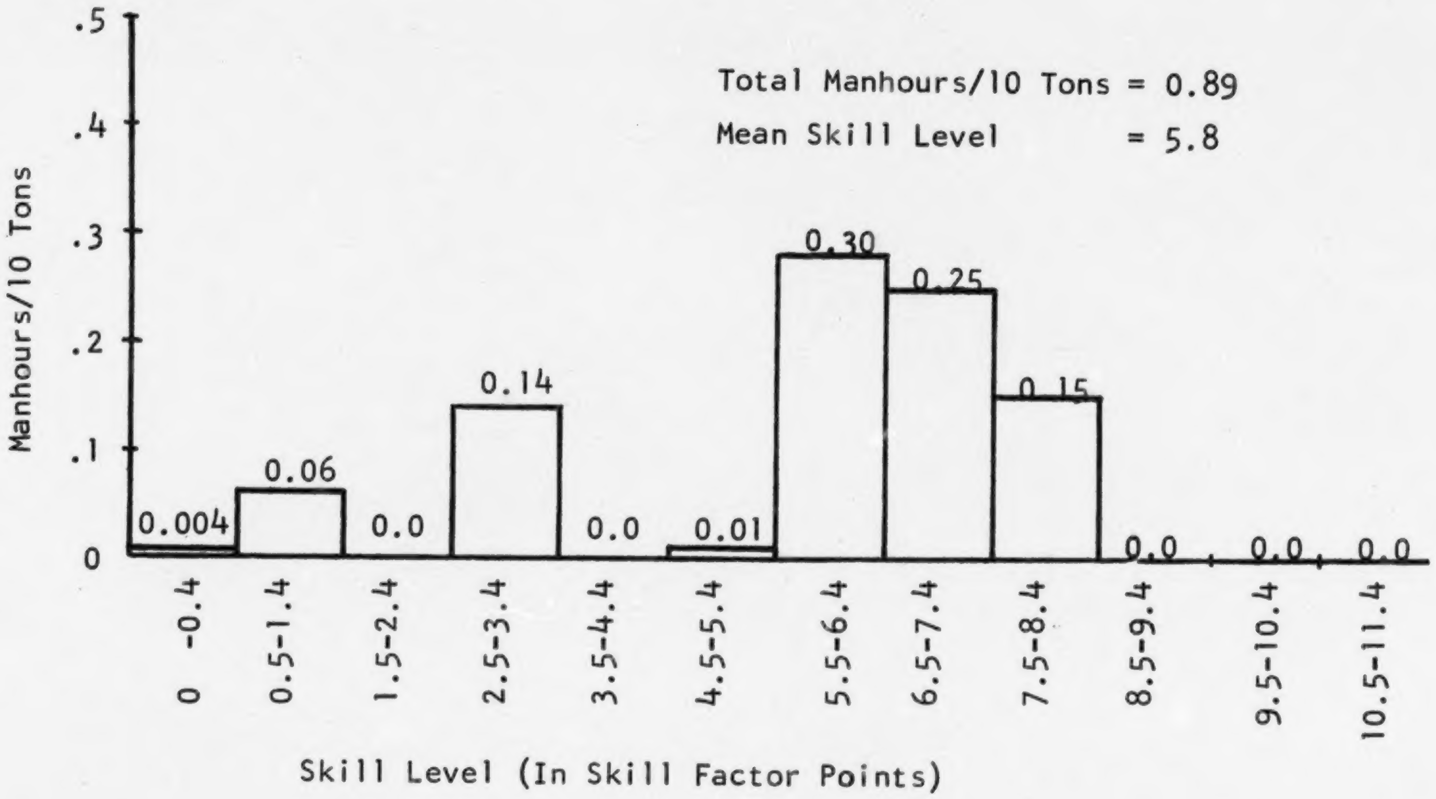
Period: September 1966 [Data Acquired - Winter 1966-1967]

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10 Tons			Manhours As % of Total for Each Technology Level			No. of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
Specialist (Craft)	10.5-11.4	0,00	0.00	0.00	0.0	0.0	0.0	0	0	0
	9.5-10.4	0.00	0.00	0.00	0.0	0.0	0.0	0	0	0
	8.5- 9.4	0.00	0.00	0.00	0.0	0.0	0.0	0	0	0
	7.5- 8.4	0.15	0.13	- 0.02	16.9	13.4	- 3.5	1	1	0
	6.5- 9.4	0.25	0.20	- 0.05	28.1	20.6	- 7.5	2	2	0
High	5.5- 6.4	0.28	0.47	+ 0.19	31.5	48.5	+17.0	1	1	0
	4.5- 5.4	0.01	0.01	0.00	1.1	1.0	- 0.1	1	1	0
Med.	3.5- 4.4	0.00	0.00	0.00	0.0	0.0	0.0	0	0	0
	2.5- 3.4	0.14	0.05	- 0.09	15.7	5.2	-10.5	1	1	0
Low	1.5- 2.4	0.00	0.00	0.00	0.0	0.0	0.0	0	0	0
	0.5- 1.4	0.06	0.10	+ 0.04	6.7	10.3	+ 3.6	1	1	0
	0.0- 0.4	0.004	0.01	+ 0.01	0.0	1.0	+ 1.0	1	1	0
	Totals	0.89	0.97	+ 0.08	100.0	100.0	0.0	8	8	0
	Net Manhour Change +9.0%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	5.8	2.0
Technology (Level 2)	5.7	2.0
Change	-1.7%	

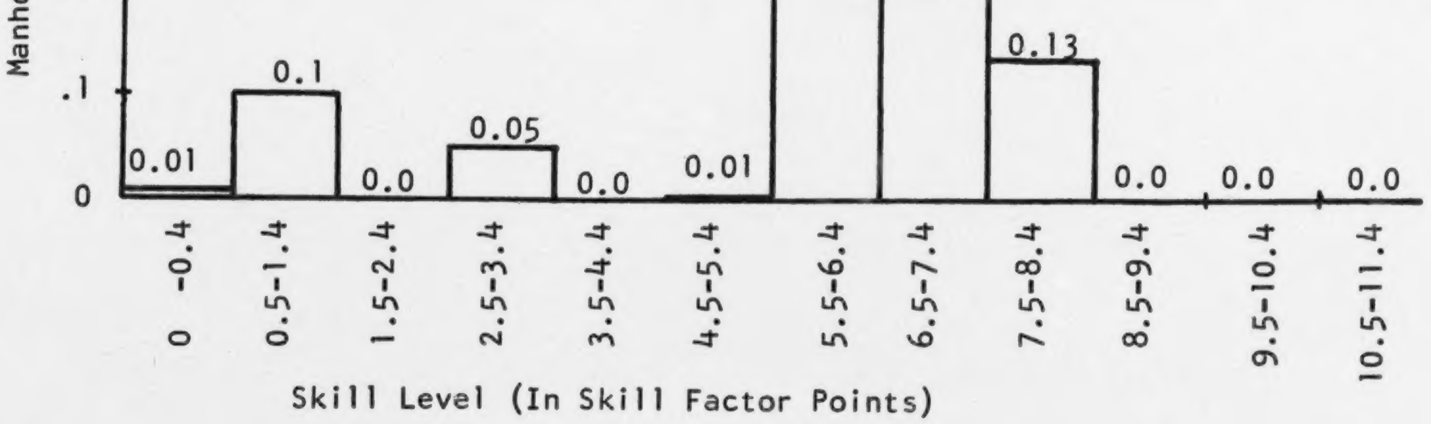
FIGURE B-3: ASSIGNED MAINTENANCE SKILL PROFILES

BATCH ANNEALING



Total Manhours/10 Tons = 0.89
Mean Skill Level = 5.8

CONTINUOUS ANNEALING



Total Manhours/10 Tons = 0.97
Mean Skill Level = 5.8

TABLE B-2: CENTRAL MAINTENANCE SKILL DISTRIBUTIONS FOR BATCH (TL1) AND CONTINUOUS (TL2) ANNEALING PROCESSES

Organization: Firm C

Process: Annealing Product Unit: 10 Tons

Technology (Level 1): Box Annealing

Technology (Level 2): Continuous Annealing

Source of Data: Company Records

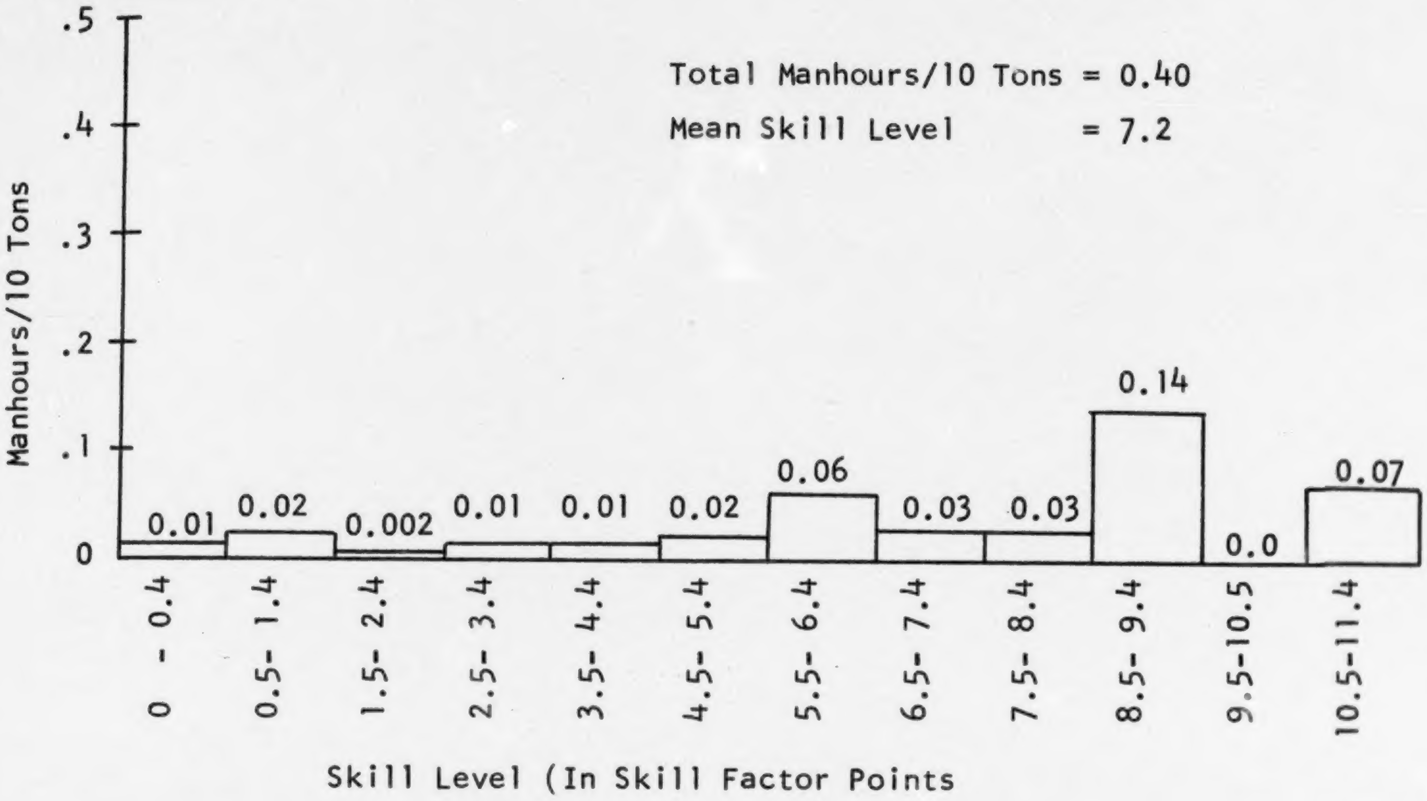
Period: September 1966 [Data Acquired - Winter 1966-1967]

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per 10 Tons			Manhours As % of Total for Each Technology Level			No. of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
Specialist (Craft)	10.5-11.4	0.07	0.11	+ 0.04	17.5	21.6	+ 4.1	1	1	0
	9.5-10.4	0.00	0.00	0.00	0.0	0.0	0.0	0	0	0
	8.5- 9.4	0.14	0.16	+ 0.02	35.0	31.4	- 3.6	3	3	0
	7.5- 8.4	0.03	0.10	+ 0.07	7.5	19.6	+12.1	5	7	+ 2
	6.5- 9.4	0.03	0.07	+ 0.04	7.5	13.7	+ 6.2	7	11	+ 4
High	5.5- 6.4	0.06	0.00	- 0.06	15.0	0.0	-15.0	1	0	- 1
	4.5- 5.4	0.02	0.02	0.00	5.0	3.9	- 1.1	3	2	- 1
Med.	3.5- 4.4	0.01	0.02	+ 0.01	2.5	3.9	+ 1.4	3	4	+ 1
	2.5- 3.4	0.01	0.01	0.00	2.5	2.0	- 1.5	3	2	- 1
Low	1.5- 2.4	0.002	0.02	+ 0.02	0.0	3.9	+ 3.9	2	3	+ 1
	0.5- 1.4	0.02	0.00	- 0.02	5.0	0.0	- 5.0	2	0	- 2
	0.0- 0.4	0.01	0.00	- 0.01	2.5	0.0	- 2.5	1	0	- 1
	Totals	0.40	0.51	+ 0.11	100.0	100.0	0.0	31	33	+ 2
	Net Manhour Change +27.5%									

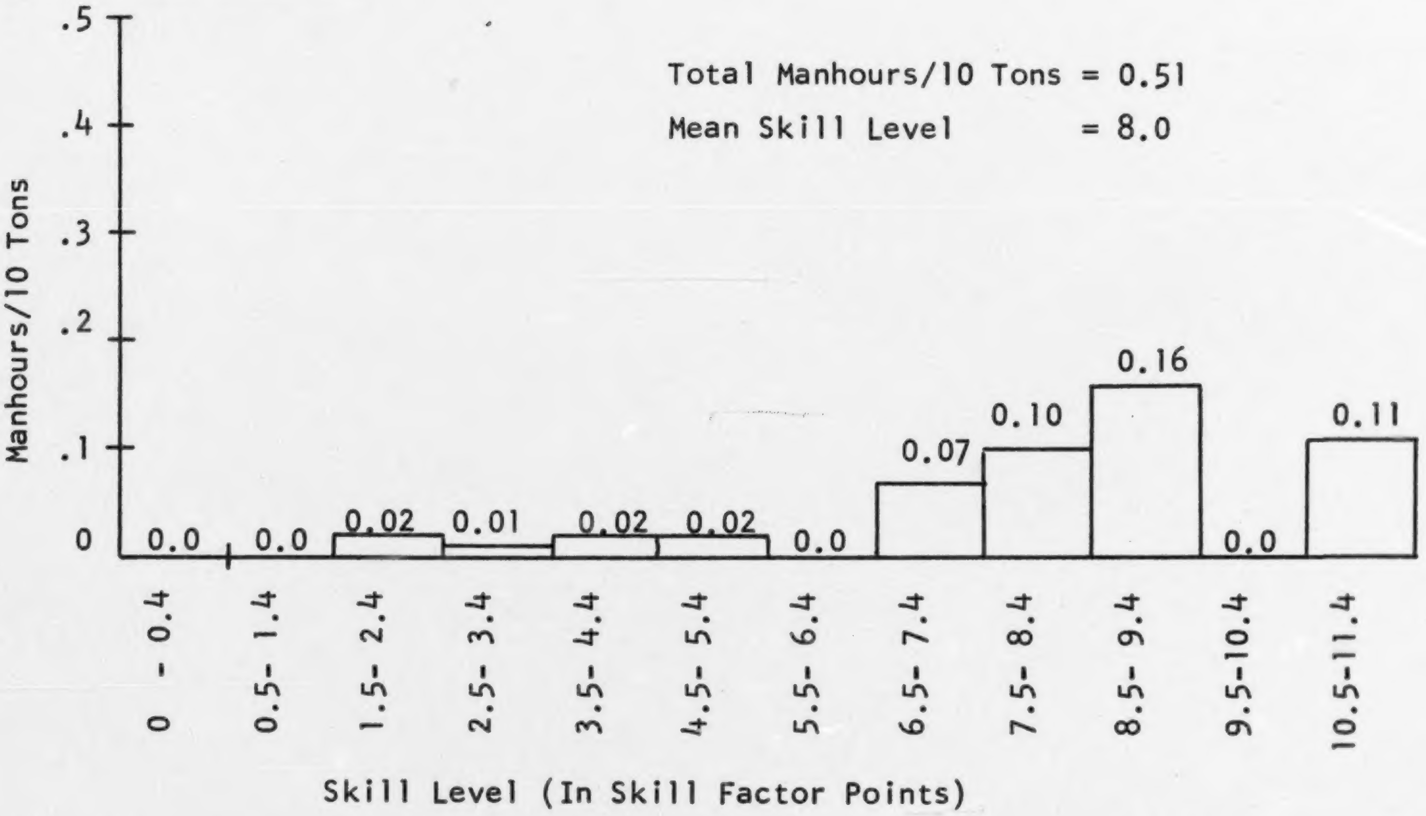
	Mean Skill Level	Standard Deviation
Technology (Level 1)	7.2	2.7
Technology (Level 2)	8.0	2.2
Change	+11.1%	

FIGURE B-4: CENTRAL MAINTENANCE SKILL PROFILES

BATCH ANNEALING



CONTINUOUS ANNEALING



3. RAW DATA USED FOR DETERMINING MANHOUR AND SKILL REQUIREMENTS

These data are tabulated under the title of each process, with the volume of product processed in parentheses. The following notes explain the meaning of each column in the tables.

Job Code	The codes are internal codes, assigned to each job to facilitate cross-referencing. The letter identifies the firm, the attached figure identifies technology and the figure separated by a dash, the job.
Job D.O.T. Number:	These six digit numbers are taken from the 1965 edition of the Dictionary of Occupational Titles. The matching of D.O.T. Number and job was done by the researchers on the basis of job description and their own knowledge of the job.
Job Title:	Official titles assigned to the jobs by the firm.
Skill Level:	Total skill factor points derived from the job evaluation scheme operative throughout the steel industry.
Manhours:	Determined by use of methodology presented in Section 2 of this Appendix.
Volumes:	Determined by reference to operating specifications and product dimensions (e.g., speed, firing time, width of product, etc) and checked with the firm's Industrial Engineering personnel.

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
C1 BOX ANNEALING				
Electrolytic Cleaning Line (Volume: 8519.6 Tons per Month)				
Assigned Maintenance				
C1a-2001	609.884	Laborer	0.0	3.0
C1a-2045	699.887	Oiler-Greaser	1.4	50.0
C1a-2041	638.884 921.883	Millwright Helper & Trac. Cr. Operator	2.8	112.0
C1a-2048	599.885	Operator - 5 - Std. Oil Cellar	5.1	6.5
C1a-2033	638.281	Millwright	6.2	234.0
C1a-2011	862.381	Pipefitter - Standard	6.6	98.0
C1a-2035	812.884	Welder - Standard	7.1	45.0
C1a-2021	829.281	Electric Wireman - Std.	8.0	118.0
Central Maintenance				
C1a-4825	710.884	Repairman, Helper - Instrument	2.5	4.0
C1a-4854	828.281	Electronic Repairman - Apprentice (3rd Per.)	3.6	2.9
C1a-4017	638.281	Brakes Repairman	4.1	4.0
C1a-4855	828.281	Electronic Repairman - Apprentice (4th Per.)	4.4	2.7
C1a-4864	710.281	Instrument Repairman - Apprentice (5th Per.)	4.5	2.8
C1a-2052	812.884	Welder - Apprentice (6th Period)	5.1	8.0
C1a-4865	710.281	Instrument Repairman - Apprentice (6th Per.)	5.4	3.1
C1a-4804	710.381	Scale Inspector	6.6	6.5
C1a-4818	626.381	Oxy-acetylene Repairman	6.7	3.2
C1a-4858	828.281	Electronic Repairman - Apprentice (7th Per.)	7.1	2.8
C1a-2078	812.884	Welder - Standard	7.1	5.0
C1a-4876	710.281	Instrument Repairman - Starting	7.6	2.9
C1a-2070	600.280	Machinist - Starting	8.5	46.0
C1a-4820	829.281	Gangleader, Instrument Repairman	9.0	4.5
C1a-4874	710.281	Instrument Repairman - Std.	9.0	40.0
C1a-4849	828.281	Electronic Repairman - Std.	10.5	41.7

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
C1 BOX ANNEALING (CONT'D)				
Box Annealing Process (Volume: 24,574.0 Tons per Month)				
Assigned Maintenance				
C1b-2001	609.884	Laborer	0.0	2.0
C1b-2045	699.887	Oiler-Greaser	1.4	1.0
C1b-2041	638.884 921.883	Millwright Helper & Trac. Cr. Operator	2.8	9.0
C1b-2033	638.281	Millwright	6.2	22.0
C1b-2011	862.381	Pipefitter - Standard	6.6	151.0
C1b-2035	812.884	Welder - Standard	7.1	43.0
C1b-2021	829.281	Electric Wireman - Std.	8.0	39.0
Central Maintenance				
C1b-2501	579.887	Laborer	0.0	24.0
C1b-2511	852.883	Operator - Concrete Breaker	0.5	4.0
C1b-2519	861.887	Bricklayer Helper	1.4	50.0
C1b-2004	600.280	Machinist Helper	1.9	2.0
C1b-7651	840.781	Painter Apprentice (2nd Period)	2.4	4.0
C1b-4825	710.884	Instrument Repairman - Helper	2.5	3.9
C1b-7916	942.883	Winch Truck Operator	2.8	1.0
C1b-2517	929.883	Tractor Operator - Brickmasons	2.8	9.0
C1b-4854	828.281	Electronic Repairman - Apprentice (3rd Per.)	3.6	2.8
C1b-4855	828.281	Electronic Repairman - Apprentice (4th Per.)	4.4	2.6
C1b-4864	710.281	Instrument Repairman - Apprentice (5th Per.)	4.5	2.7
C1b-2052	812.884	Welder Apprentice - (6th Period)	5.1	5.0
C1b-4865	710.281	Instrument Repairman - Apprentice (6th Per.)	5.4	3.0
C1b-7670	840.781	Painter - Standard	5.8	134.4
C1b-4804	710.381	Scale Inspector	6.6	6.3
C1b-5021	637.281	Gangleader - Air Cond. & Refigeration	6.6	3.0
C1b-5022	637.281	Air Conditioning & Refigeration Repairman	6.6	5.0
C1b-7970	921.280	Rigger-Standard	6.6	5.0
C1b-4818	626.381	Oxy-Acetylene Repairman	6.7	3.1

C1 BOX ANNEALING (CONT'D)

Box Annealing Process (Cont'd)

Central Maintenance (Cont'd)

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
C1b-4858	828.281	Electronic Repairman - Apprentice (7th Per.)	7.1	2.7
C1b-2078	812.884	Welder - Standard	7.1	2.0
C1b-4876	710.281	Instrument Repairman - Starting	7.6	2.8
C1b-7316	860.281	Gangleader - Carpenter	7.9	4.0
C1b-7370	860.281	Carpenter - Standard	7.9	9.0
C1b-2570	861.381	Bricklayer - Standard	7.9	52.0
C1b-4070	824.281	Electric Wireman - Std.	8.0	3.0
C1b-2070	600.280	Machinist - Standard	8.5	62.0
C1b-4820	829.281	Gangleader - Instrument Repairman	9.0	4.4
C1b-4874	710.281	Instrument Repairman - Standard	9.0	38.2
C1b-4849	828.281	Electronic Repairman - Standard	10.5	40.2

C2 CONTINUOUS ANNEALING (Volume: 20,365.7 Tons Per Month)

Assigned Maintenance

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
C2-2001	609.884	Laborer	0.0	30.0
C2-2045	699.887	Oiler-Greaser	1.4	150.5
C2-2041	638.884 921.883	Millwright Helper & Trac. Cr. Operator	2.8	111.0
C2-2048	599.885	Operator - 5 - Std. Oil Cellar	5.1	11.0
C2-2033	638.281	Millwright	6.2	956.8
C2-2011	862.381	Pipefitter - Standard	6.6	275.8
C2-2035	812.884	Welder - Standard	7.1	125.0
C2-2021	829.281	Electric Wireman - Std.	8.0	265.0

Central Maintenance

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
C2-4250	824.281	Electric Wireman - Apprentice (1st Per.)	1.6	8.0
C2-2004	600.280	Machinist Helper	1.9	6.0
C2-4051	824.281	Electric Wireman - Apprentice (2nd Per.)	2.3	21.0
C2-4825	710.884	Instrument Repairman - Helper	2.5	21.0

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
C2 CONTINUOUS ANNEALING (CONT'D)				
Central Maintenance (Cont'd)				
C2-2055	600.280	Machinist - Apprentice (3rd Period)	3.0	3.0
C2-5053	862.381	Pipefitter - Apprentice (4th Period)	3.3	8.0
C2-4854	828.281	Electronic Repairman - Apprentice (3rd Per.)	3.6	15.0
C2-4030	921.280	Extra Craneman	3.6	2.0
C2-4855	828.281	Electronic Repairman - Apprentice (4th Per.)	4.4	13.8
C2-4864	710.281	Instrument Repairman - Apprentice (5th Per.)	4.5	14.6
C2-4865	710.281	Instrument Repairman - Apprentice (6th Per.)	5.4	15.9
C2-2060	600.280	Machinist - Apprentice (8th Period)	6.5	2.0
C2-4804	710.381	Scale Inspector	6.6	34.0
C2-5070	862.381	Pipefitter - Standard	6.6	31.0
C2-7911	921.280	Gangleader - Rigger	6.6	1.0
C2-7970	921.280	Rigger - Standard	6.6	20.0
C2-4818	626.381	Oxy-Acetylene Repairman	6.7	16.9
C2-2078	812.884	Welder - Standard	7.1	8.0
C2-4858	828.281	Electronic Repairman - Apprentice (7th Per.)	7.1	14.7
C2-5025	862.381	Gangleader - Pipe Shop	7.1	2.0
C2-5078	812.884	Welder - Standard	7.1	8.0
C2-7978	812.884	Welder - Standard	7.1	8.0
C2-4876	710.281	Instrument Repairman - Starting	7.6	15.1
C2-7370	860.281	Carpenter - Standard	7.9	1.0
C2-2026	600.280	Gangleader - Machinist	8.0	4.0
C2-4011	829.281	Gangleader - Wireman Electrician	8.0	4.0
C2-4070	824.281	Electric Wireman - Std.	8.0	68.0
C2-4211	829.281	Gangleader, Wireman Electrician	8.0	4.0
C2-4270	829.281	Wireman Electrician - Standard	8.0	104.0
C2-2070	600.280	Machinist - Standard	8.5	108.0
C2-4874	710.281	Instrument Repairman - Standard	9.0	205.5
C2-4820	829.281	Gangleader - Instrument Repairman	9.0	23.5
C2-4849	828.281	Electronic Repairman - Standard	10.5	216.5

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
C1 BOX ANNEALING				
Electrolytic Cleaning Line (Volume: 239.4 Tons Per Shift)				
C1-1S	619.130	Turn Foreman - Cold Rolling & Cleaning	8.6**	1.0
C1-2S	183.168	General Foreman - Cold Rolling & Cleaning	10.2**	0.0
Box Annealing Process (Volume: 800 Tons Per Shift*)				
C1-3S	504.131	Turn Foreman - Annealing	8.6**	8.0
C1-4S	183.168	Assistant General Foreman - Annealing	10.2**	0.8
C1-5S	183.168	General Foreman - Annealing	10.2**	0.8
C2 CONTINUOUS ANNEALING (Volume: 325.2 Tons Per Shift)				
C2-1S	504.131	Turn Foreman - Annealing	8.6**	8.0
C2-2S	183.168	Assistant General Foreman - Annealing	10.2**	1.2*
C2-3S	183.168	General Foreman - Annealing	10.2**	1.2*
C1 BOX ANNEALING				
Electrolytic Cleaning Line (Volume: 239.4 Tons Per Shift)				
C1-1p	221.388	Mill Clerk - Cold Reduction (1/day@1hr)	2.3**	0.25***
C1-2p	012.188	Scheduler - Cold Reduction (1/day@1hr)	3.3**	0.25***

---

* Calculated on the basis of 20 shifts per week

** Estimated by Researchers

***Based on 5 days per week and 20 shifts per week

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
C1 BOX ANNEALING (CONT'D)				
Box Annealing Process (Volume: 800 Tons Per Shift)				
C1-3p	221.388	Mill Clerk - Cold Reduction (1/day@4hrs)	2.3**	0.25
C1-4p	012.188	Scheduler - Box Annealing (1/day@4hrs)	3.3**	1.0
C2 CONTINUOUS ANNEALING (Volume: 325.2 Tons Per Shift)				
C2-1p	221.388	Mill Clerk - Cold Reduction (1/day@6Hrs)	2.3**	1.50***
C2-2p	012.188	Scheduler - Annealing (1/day@8hrs)	3.3**	2.00***

** Estimated by Researchers

***Based on 5 days per week and 20 shifts per week

APPENDIX C

POWER PRODUCTION BY STEAM-ELECTRIC PROCESS

1. OUTLINE OF TECHNOLOGY

Power plant operations can best be understood in terms of three flow circuits (see Figure C-1). In the first circuit fuel (oil and/or natural gas in the plants discussed in this report) is mixed with air, combustion of the mixture taking place in a furnace. Combustion heats up the steam condensate in the boiler tubes passing through the furnace (see main circuit) and the high temperature, high pressure steam generated in this process supplies the energy for the propulsion of the turbine activating the generator shaft. Having given up the best part of its energy, the steam travels to the condenser from which it emerges as condensate. Condensation is effected through exposing the spent steam to the cooling action of river, ocean or lake water (circuit at bottom of diagram). Before entering the furnace, the condensate is normally pre-heated.

What lends the critical element to the operation of relative simple equipment is the requirement for rapid response to continual and at times very large changes in demand. It is this requirement which calls for a consistently high standard of control and regulation. The following description of the impact of changes in demand on the operating equipment may help to convey a notion of the potential consequences of sub-standard control.

Any increase in energy requirements reduces the resistance of the system and a greater current immediately flows through the generator armature and intermediate circuit. This higher current flow increases the magnetic field strength of the armature, thus resisting turning of the generator rotor. Consequently, there is an immediate drop in generator and turbine shaft speed. The turbine governor then goes into action, the turbine steam-admission valves begin to open and more steam flows into the turbine. However, because energy input to the furnace has not changed, the steam pressure begins to drop.

Pressure reduction signals the operator or the automatic combustion-control system to speed up the various draft fans and the fuel feed system. The increased heat release in the furnace checks the rate of pressure drop, and the governor reaches a balance point to hold the higher load at a speed slightly less than normal. Adjustment of the governor spring tension opens the throttle valve a little more, thus increasing steam flow and bringing shaft speed back to normal. As pressure nears its set value firing eases off, overshooting slightly to restore balanced conditions more rapidly. The total time for the changes listed in this and the previous paragraph may be anywhere from a few seconds to a few minutes, depending on the size of the load change.

When there is a decrease in energy requirements, the magnetic forces between the rotor and armature reduce and the rotor speeds up. The governor then partly closes the steam admission valve, reducing steam flow and raising steam pressure; in their turn, the draft fan and fuel flow systems are slowed down. The governor reaches a balance point where the lower load is held at a slightly higher shaft speed. The governor spring tension is then adjusted, which closes the throttle valve further, lowers steam flow, and brings shaft speed back to normal.

The firing rate then allows pressure to drop to its normal value.

The above description does not include other adjustments that must be made in the plant cycle; e.g., water levels in the boiler drum, condenser hotwell and feedwater heaters, furnace pressures, and pump speeds. Nor does the description adequately capture the full complexity of the control and regulation process. To do it justice, an information flow diagram is shown in Figure C-2 which includes the main components of a supervisory control system in a computerized generating plant.

At scheduled intervals, station units are shut down completely for inspection, overhaul, and repair, after which they must go through a controlled start-up routine which synchronizes them to the bus or load. As precision of timing, speed and coordination of control activities are absolutely vital in the shut down and particularly in the start-up procedures, the crews are fully extended during these operations. It is a measure of their critical nature that these operations were the first to be transferred from human control to closed loop computer control when computers were introduced in generating plants.

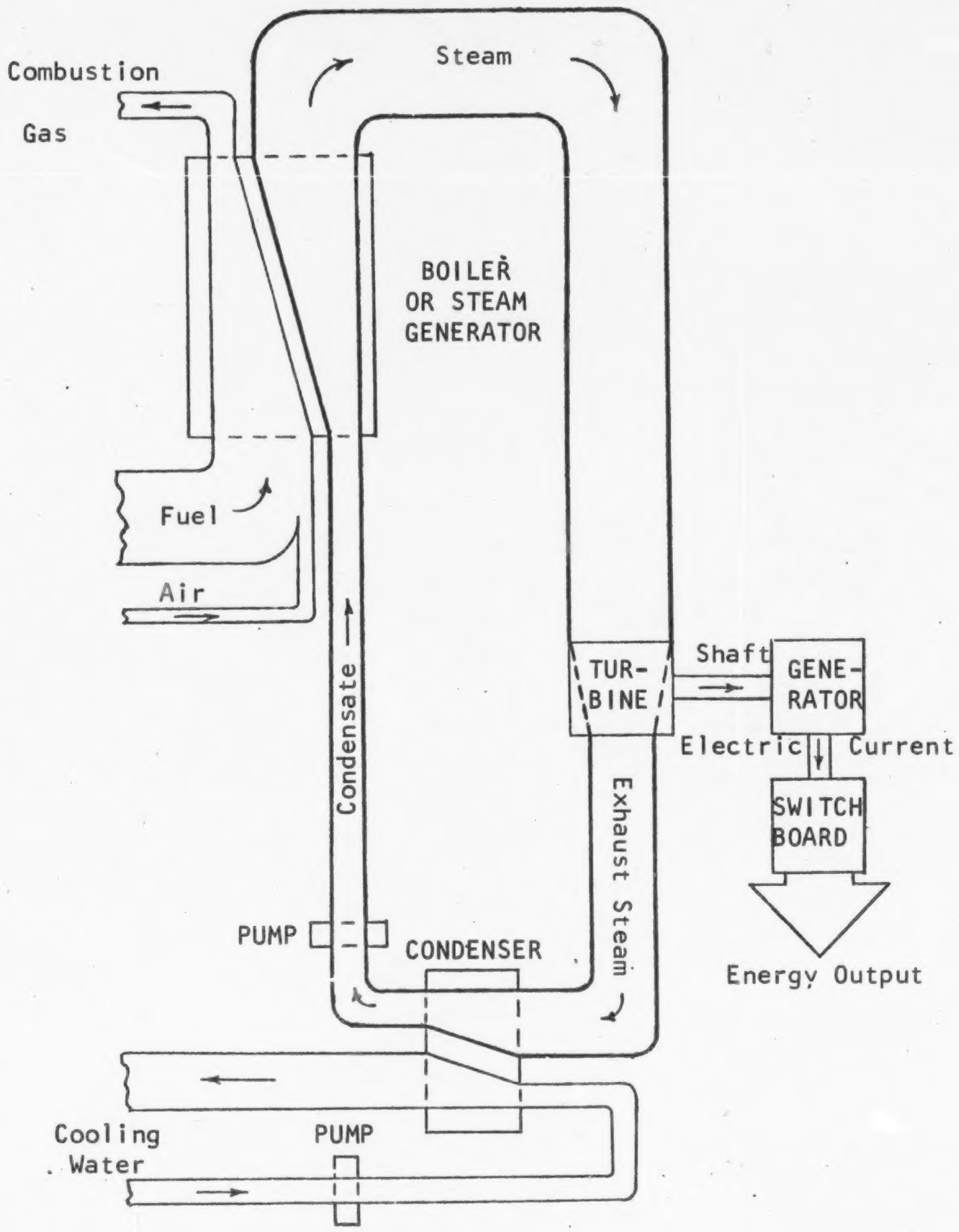

Combustion
Gas
Steam
BOILER
OR STEAM
GENERATOR
Fuel
Air
Condensate
TUR-
BINE
Shaft
GENE-
RATOR
Electric
Current
SWITCH
BOARD
Energy Output
Exhaust Steam
PUMP
CONDENSER
Cooling
Water
PUMP

FIG. C-1: SIMPLIFIED POWER PLANT FLOW-CIRCUIT

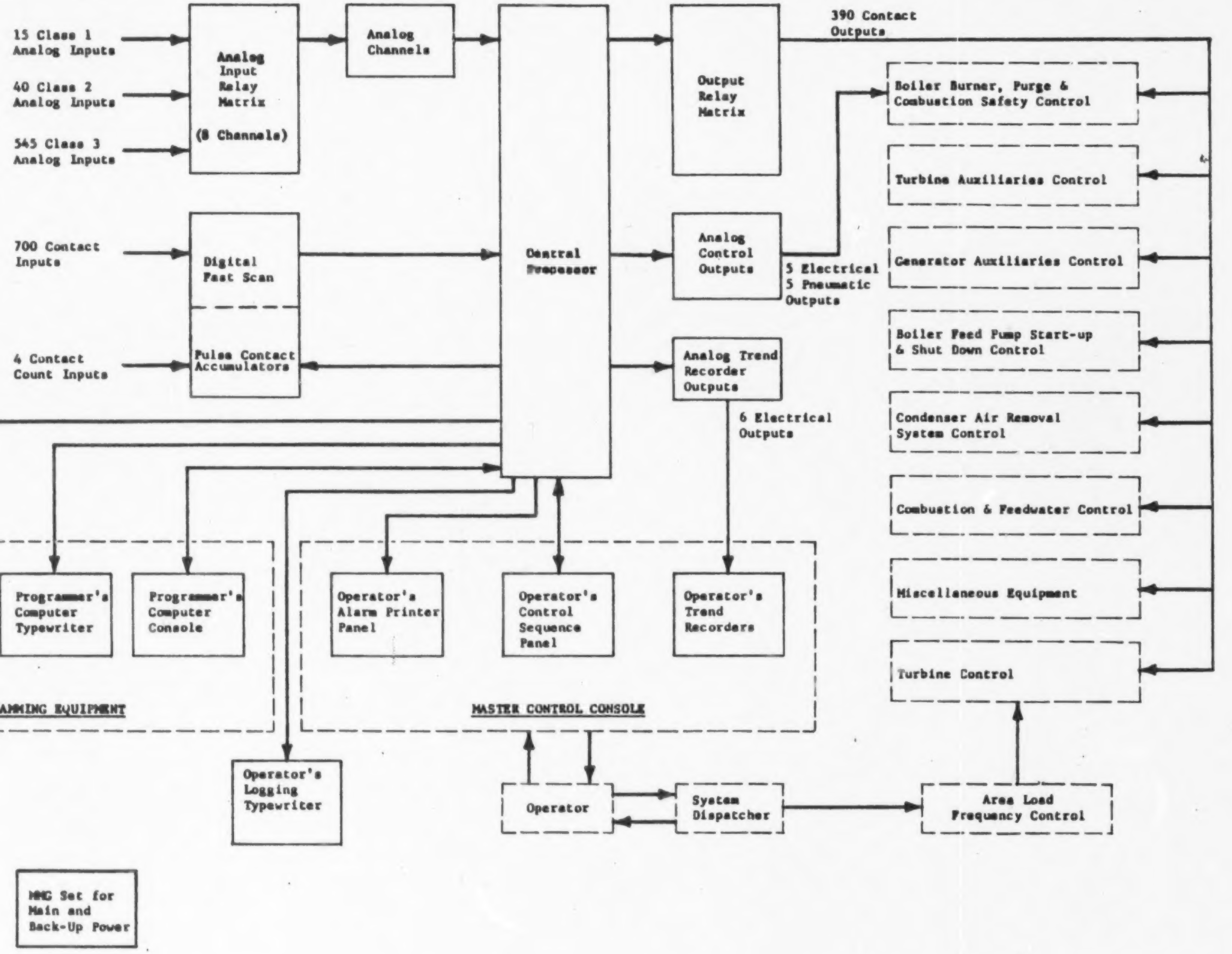

15 Class 1 Analog Inputs
40 Class 2 Analog Inputs
545 Class 3 Analog Inputs
Analog Input Relay Matrix (8 Channels)
Analog Channels
700 Contact Inputs
Digital Fast Scan
4 Contact Count Inputs
Pulse Contact Accumulators
Central Processor
Output Relay Matrix
390 Contact Outputs
Analog Control Outputs
5 Electrical 5 Pneumatic Outputs
Analog Trend Recorder Outputs
6 Electrical Outputs
Boiler Burner, Purge & Combustion Safety Control
Turbine Auxiliaries Control
Generator Auxiliaries Control
Boiler Feed Pump Start-up & Shut Down Control
Condenser Air Removal System Control
Combustion & Feedwater Control
Miscellaneous Equipment
Turbine Control
Programmer's Tape Reader Tape Punch
Programmer's Computer Typewriter
Programmer's Computer Console
PROGRAMMING EQUIPMENT
Operator's Alarm Printer Panel
Operator's Control Sequence Panel
Operator's Trend Recorders
MASTER CONTROL CONSOLE
Operator's Logging Typewriter
Operator
System Dispatcher
Area Load Frequency Control
MMG Set for Main and Back-Up Power

FIGURE C-2: COMPONENTS OF AN AUTOMATIC SUPERVISORY CONTROL SYSTEM IN A GENERATING PLANT

2. DESCRIPTIONS OF THE PLANTS STUDIED

Plants J1 (Non-Centralized) and J2a (Centralized)

Plant J1 was built in 1949 and until 1954 was non-centralized, with operators stationed remotely at boiler, turbine, and boiler feed pump control panels, and at various auxiliary equipment locations. Centralization of the plant (Study J2a) was effected partly by duplicating all remotely located control panels in a central control room.

The automatic controls in power plant J1 included pneumatic positioning devices which were actuated by pneumatic controllers mounted on local control boards situated as close as practicable to the operating equipment: seven combustion control boards distributed along a firing aisle serving the seven boilers; four turbine gage boards at two locations on the turbine deck; four condensate and boiler feed boards at two different locations in the vicinity of the pumps; and two circulating water gage boards.

Plant J1 also had a centrally located electrical control room that contained the electrical switchboards for the main generators, the switchboard for battery control and direct-current distribution, and the telephone and oscillograph equipment. This electrical control room was later extended and remodelled to become the central control room for the centralized power plant J2a.

Figure C-3 indicates the control positions before centralization (J1). The orientation of the control panels in the centralized plant (J2a) are shown in Figure C-4. The individual turbine panels in Figure C-4 contain all essential instruments and controls for the turbine, the circulating water system, and the condensate and feed water systems for one unit. Corresponding generator panels are on the right. The station master-panel includes the master controls for the seven boilers, motor control switches for common plant facilities, and appropriate instruments and annunciators. The individual boiler panels consist of a benchboard console containing controls and supervisory instruments and a detached vertical panel with recorders, television receivers for burner and drum-level viewing, and annunciator panels.

The instruments and controls for the boiler cleaning-lance controls, fuel-oil pump sequence selectors, generator hydrogen controls and evaporator controls are not in the centralized control room. This equipment is operated by three roving Plant Equipment Operators, but abnormal conditions are annunciated in the central control room.

Several control features were added when the original plant (J1) was centralized (J2a); they were so placed as to allow the control room operator to change from automatic to remote-manual operation. Television drum-level monitors replaced sight ducts on the boilers. Television viewing of the six burners on each boiler was also added to give the control room operator a direct view of the flame pattern during operation and of burner behavior during remote ignition or quick fuel changeover. Changeover from natural gas fuel to oil fuel was originally accomplished at the local combustion control boards and by the manipulation of valving at the burner front. With centralized control remote-controlled devices were provided to allow fuel changes directly from the central control room.

Automatic bearing temperature scanning systems and temperature control systems were also added when the plant was centralized. The bearings of the main turbine-generators, house turbine-generators, forced and induced draft fans, boiler feed pumps and condensate booster pumps can now be monitored. Finally, automatic temperature control systems replaced manual valving at the lube oil and condensate coolers.

Plant J2b (Centralized)

Was completed in 1957 and is at the same control technology level as plant J2a. It is worth noting that the main difference between J2a and J2b is physical size. Plant size determines the number of roving plant equipment operators, as some instruments and controls are not in the centralized control room and must be monitored or operated remotely.

The physical layout and size of the J2b centralized control room is not the same as that of J2a; however, the operation of the J2b plant is similar to that of the J2a plant.

Plant J3 (Centralized/Computerized)

Built in 1963 and controlled from a central control room, it utilizes two General Electric 412 digital computers (with 56,000 word drum and 8000 word core memory) for start-up, shutdown, control and continuous plant monitoring.

The start-up and normal shutdown programs are the major computer-controlled operating sequences. These sequences, once initiated by the operator, will stop only when an abnormal condition develops. If in the operator's judgement corrective action is not required, he may reinitiate the sequence with an override push button. During normal operation the plant is controlled by sub-loops and the computer takes controlling action only if the abnormal conditions arise. All other programs in the computer are routines which may be in service any time the computer is supervising operations. During start-up or shutdown, several routines may be in operation concurrently with the main programs. In general, routines are called up automatically when a particular set of conditions exist, and are automatically withdrawn when the intended action is complete or when the computer instructs the routines to stop.

Other computer routines aside from the start-up and normal shutdown program, are as follows:

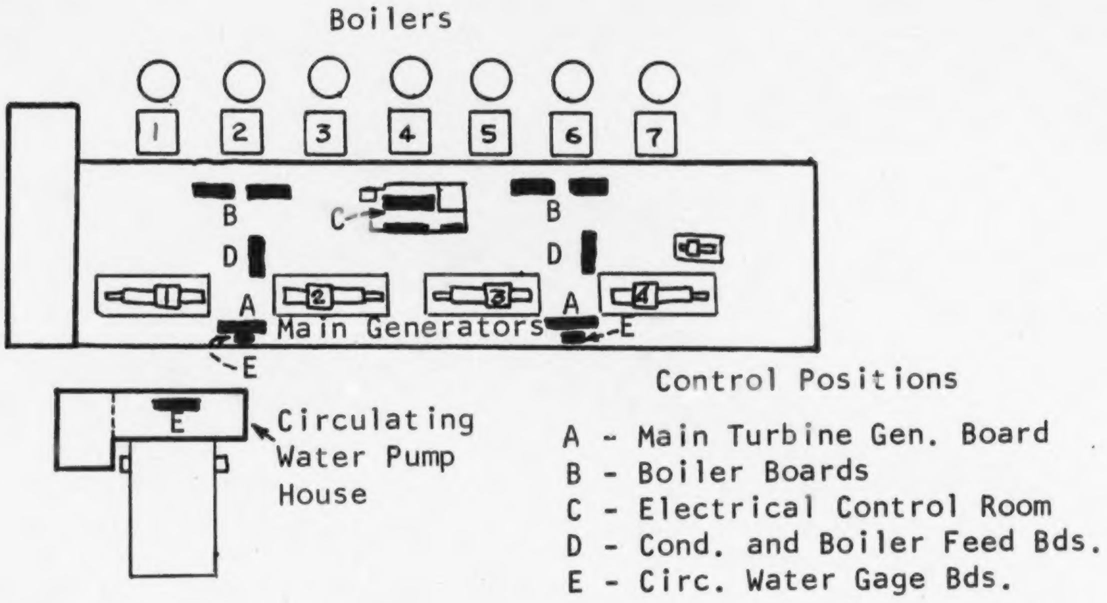

Boilers
1
2
3
4
5
6
7
B
C
B
D
D
A
A
Main Generators
E
E
E
Circulating Water Pump House
Control Positions
A - Main Turbine Gen. Board
B - Boiler Boards
C - Electrical Control Room
D - Cond. and Boiler Feed Bds.
E - Circ. Water Gage Bds.

FIG C-3: LOCATION OF CONTROL PANELS IN NON-CENTRALIZED POWER PLANT

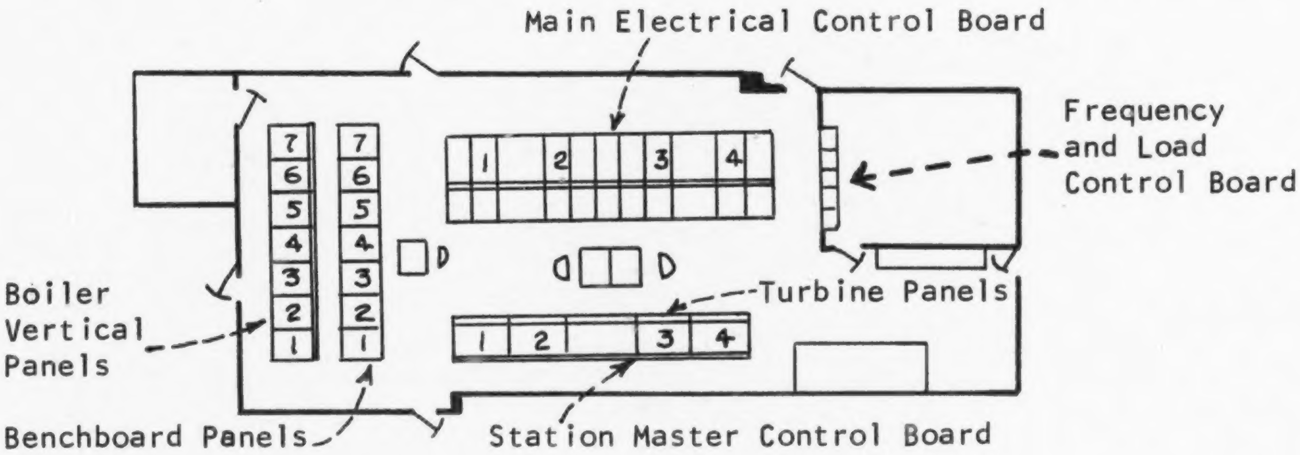

Main Electrical Control Board
Frequency and Load Control Board
1
2
3
4
Turbine Panels
1
2
3
4
7
6
5
4
3
2
1
7
6
5
4
3
2
1
Boiler Vertical Panels
Benchboard Panels
Station Master Control Board

FIG. C-4: LAYOUT OF CONTROL ROOM IN CENTRALIZED PLANT

1. Emergency shutdown routines (ESD) - initiated by the computer or by conventional control sub-loop tripping devices after a full or partial unit trip.
2. Sensing and regulating routines (S & R) - function during start-up and shutdown to effect regulating action based on feedback information.
3. Diagnostic and corrective action routines - take corrective action for off-normal conditions resulting from malfunction of controls or equipment.
4. Fuel change routines - initiated by operator to change boiler fuels.
5. Special scanning routines - initiate corrective action for alarm conditions.

In addition to the above listed routines, the computer system provides operators with annunciation of off-normal conditions. Also, plant calculations are made on the basis of information from computer input sensors, and their results are stored for use by other programs along with other critical plant variables.

Plant K1 (Non-Centralized)

Was built in 1930 and is at the same control technology level as plant J1. K1 is a non-centralized system with operators stationed remotely at boiler, turbine, and boiler feed-pump control panels, and also, on a roving basis, at various auxiliary equipment locations. Figure C-5 indicates the locations of the control panels.

Plant K2 (Centralized)

Built in 1961 and operated from a centralized control room similar to plants J2a and J2b.

Plant K3 (Centralized/Computerized)

Built in 1964 and similar to power plant J3, K3 is controlled from a centralized control room and utilizes a Westinghouse (Sperry Rand) PRODAC 510 digital computer, with 65,536 word drum and 8,192 word core memory.

Computer programs in order of descending priority, as defined by Firm K, are as follows:

1. Diagnostic Programs - highest priority program which prints diagnostic messages on the programmer's console.

2. Alarm Programs - inform operators by audible and/or visual annunciation of alarm conditions found by the analog or digital scan programs.

3. Analog Scan Programs - scanned analog voltages are converted to engineering units and stored for later use by other programs.

4. Digital Scan and Periodic Programs - stores the scanned status of some 600 contact inputs for later use by other programs.

5. Control Programs - four programs used specifically for closed loop computer control of plant operations:

    a) Turbine Start-Up Program
    b) Boiler Purge and Gas Cock Program
    c) Steam Air Heater Temperature Control Program
    d) Valve Point Loading Program

6. Operators' Console Programs - comprise 17 possible programs for selected computations, calibrations, printout and visual process reviews, etc. All programs are initiated through push buttons on the operator's console.

7. Performance Calculations - comprise about 30% of all program instructions within the computer. Calculated values are stored for use in Operator's Console Programs, the hour log, and 24 hour log printout program. Performance indices calculated include heat rates, efficiencies, etc.

8. Off-Line Programs - entered into computer through the programmer's console but not related to other programs within the computer. Most programs written are used in conjunction with unit operation and utilize values stored by other programs.

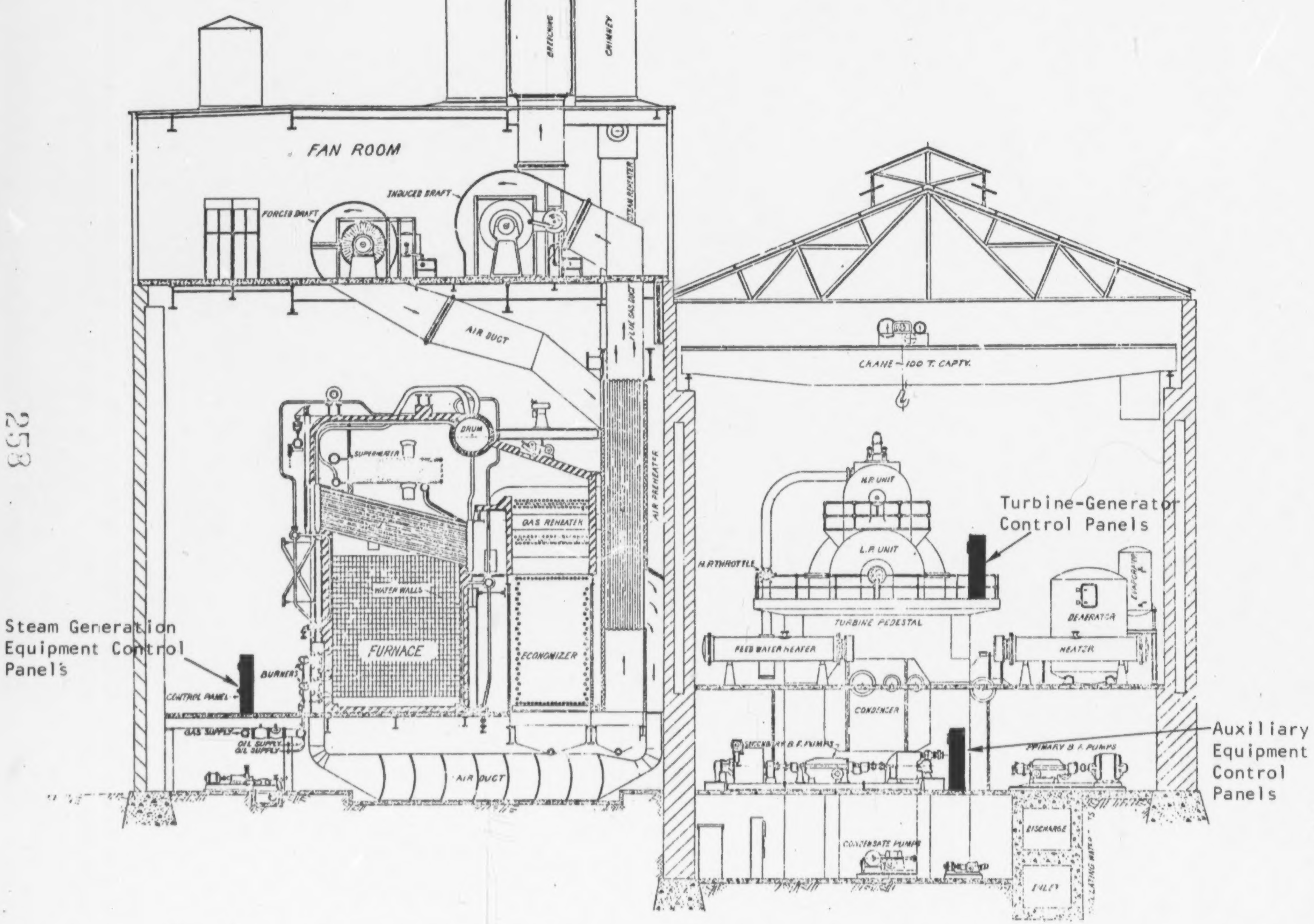
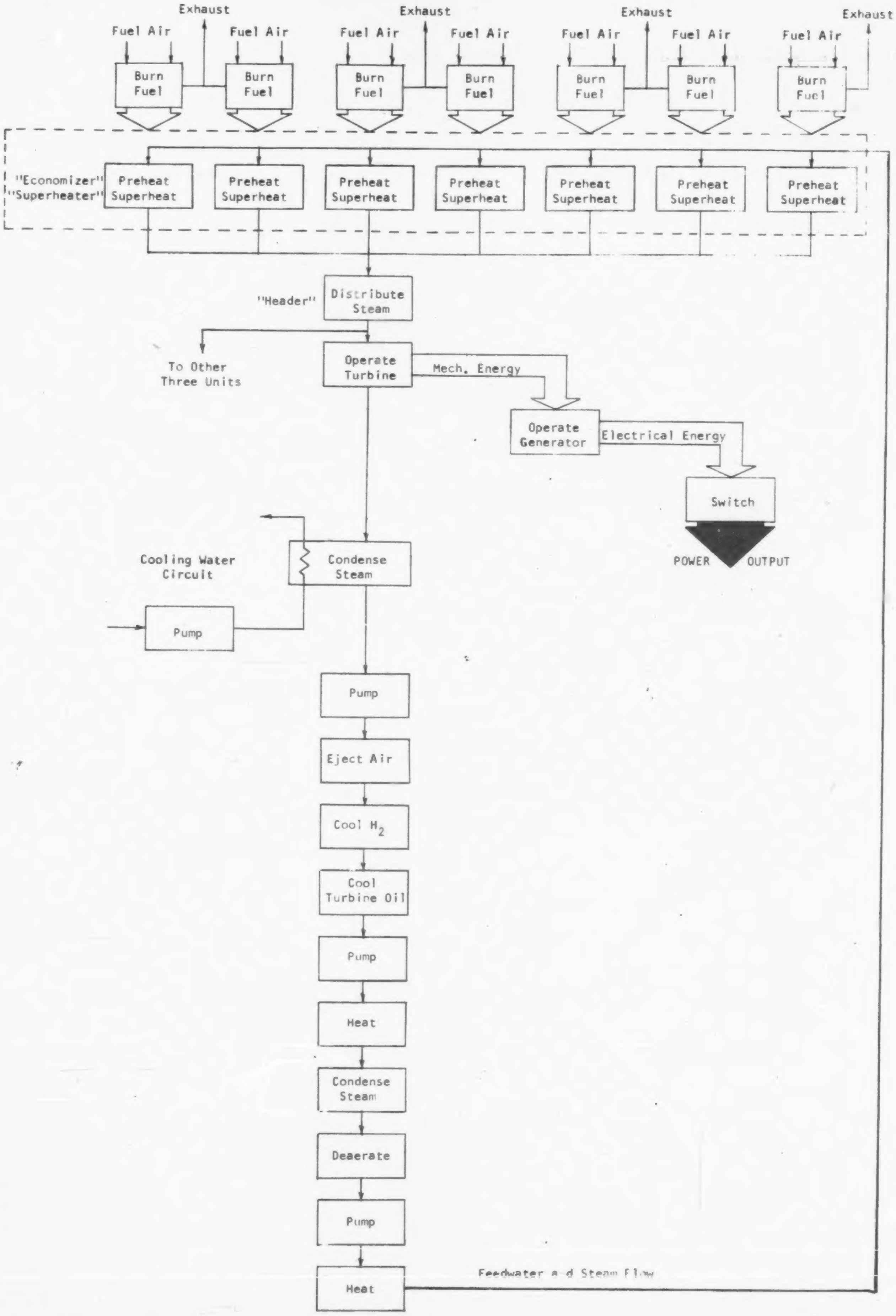

FAN ROOM
BREECHING
CHIMNEY
INDUCED DRAFT
FORCED DRAFT
STEAM REHEATER
AIR DUCT
FLUE GAS DUCT
AIR PREHEATER
DRUM
SUPERHEATER
GAS REHEATER
WATER WALLS
FURNACE
ECONOMIZER
BURNERS
CONTROL PANEL
GAS SUPPLY
OIL SUPPLY
OIL SUPPLY
AIR DUCT
CRANE – 100 T. CAPTY.
H.P. UNIT
L.P. UNIT
H.P. THROTTLE
TURBINE PEDESTAL
FEED WATER HEATER
DEAERATOR
EVAPORATOR
HEATER
CONDENSER
SECONDARY B. F. PUMPS
PRIMARY B. F. PUMPS
CONDENSATE PUMPS
DISCHARGE
INLET
Steam Generation Equipment Control Panels
Turbine-Generator Control Panels
Auxiliary Equipment Control Panels

FIG. C-5: LOCATIONS OF CONTROL PANELS IN NON-CENTRALIZED POWER PLANT (SWITCHING ROOM NOT SHOWN)

FIGURE C-6: POWER PLANT J1 - EQUIPMENT, CONTROL LOCATIONS AND OPERATORS

Simplified Process Flow Diagram


Exhaust
Fuel Air
Burn Fuel
"Economizer"
"Superheater"
Preheat Superheat
"Header"
Distribute Steam
To Other Three Units
Operate Turbine
Mech. Energy
Operate Generator
Electrical Energy
Switch
POWER OUTPUT
Cooling Water Circuit
Condense Steam
Pump
Eject Air
Cool H_2
Cool Turbine Oil
Heat
Deaerate
Feedwater and Steam Flow

Unit Equipment		Control Locations[*2] and Operators	
Furnaces Boilers	Steam[*1] Generators	**E** **N** (4 Control Panels, 1 Panel per Pair Steam Generators, Plus 1 Panel for 7th Steam Generator)	1st Boiler Operator Boiler Operator
Turbine Generator	Turbine Generator Unit	**E** **N** (2 Control Panels, 1 Panel per Pair Turbine-Generators)	1st Turbine Operator Turbine Operator
Switchboard		**C**	Switchboard Operator - Steam
Condenser Circulation Pump Condensate Pump Air Ejector Condenser Hydrogen Cooler Turbine Oil Cooler Booster Pump Heaters Evaporation Condenser Deaerator Boiler Feed Pump Heaters		**E** **N** (2 Control Panels, 1 Panel per Pair Turbine-Generators Auxiliary Equipment)	1st Auxiliary Operator 2nd Auxiliary Operator

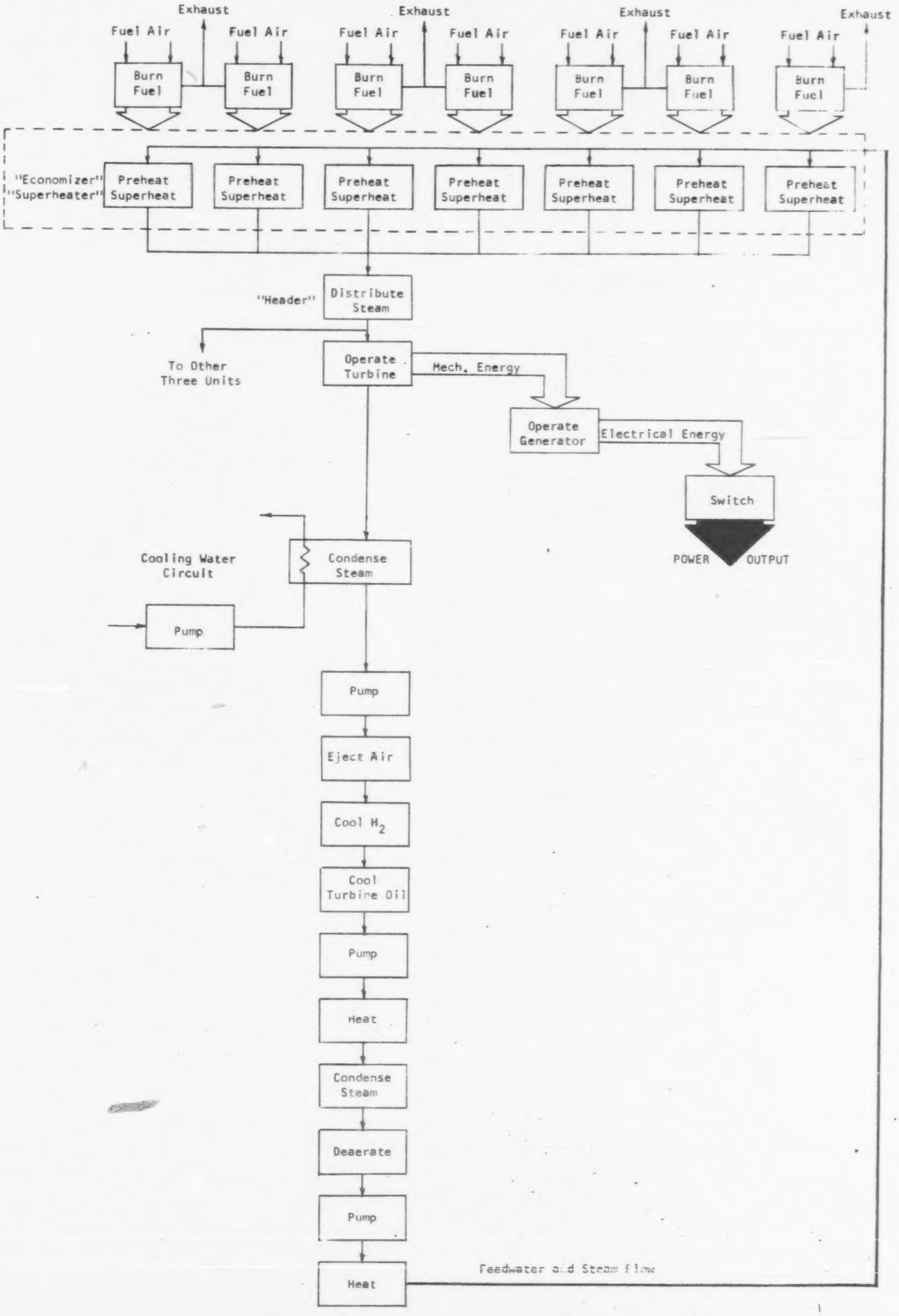
---

[*1] The Plant has seven Steam Generators feeding into common header, which in turn feeds four Turbine-Generators.

[*2] Control Locations:
E - Plant Equipment Itself
N - Control Panel in Equipment Area (Non-Centralized)
C - Control Panel in Central Control Room (Centralized)

FIGURE C-7: POWER PLANT J2a - EQUIPMENT, CONTROL LOCATIONS AND OPERATORS

Simplified Process Flow Diagram


Exhaust
Fuel Air
Burn Fuel
"Economizer"
"Superheater"
Preheat Superheat
"Header"
Distribute Steam
To Other Three Units
Operate Turbine
Mech. Energy
Operate Generator
Electrical Energy
Switch
POWER OUTPUT
Cooling Water Circuit
Condense Steam
Pump
Eject Air
Cool H_2
Cool Turbine Oil
Heat
Deaerate
Feedwater and Steam Flow

Unit Equipment		Control Locations[2] and Operators	
Furnaces Boilers	Steam[1] Generators	E - Plant Equipment Operator	C - Control Operator Assistant Control Operator
Turbine Generator	Turbine Generator Units	E - Plant Equipment Operator	
Switchboard			
Condenser Circulation Pump Condensate Pump Air Ejector Condenser Hydrogen Cooler Turbine Oil Cooler Booster Pump Heaters Evaporation Condenser Deaerator Boiler Feed Pump Heaters		E - Plant Equipment Operator	

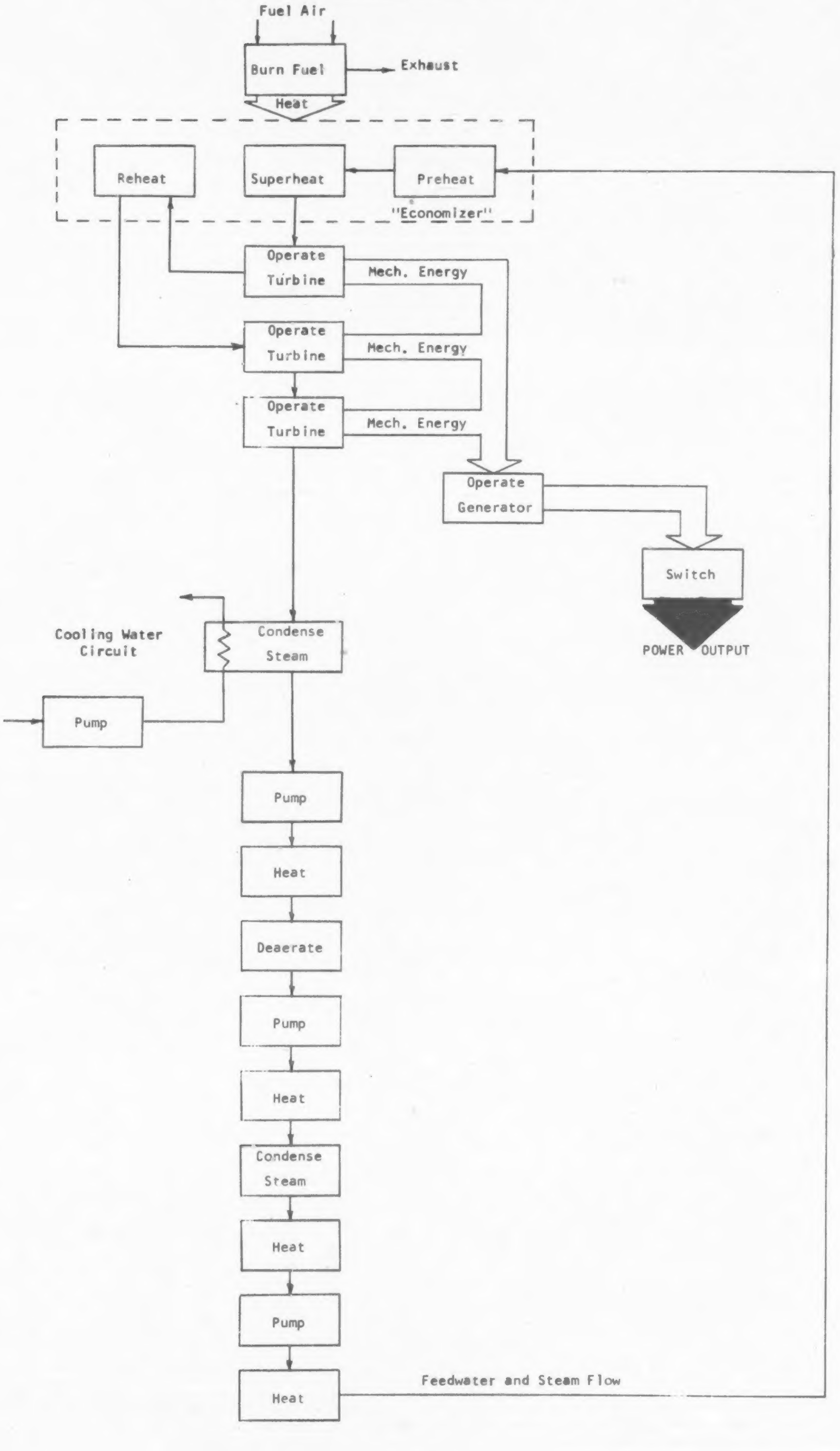
---

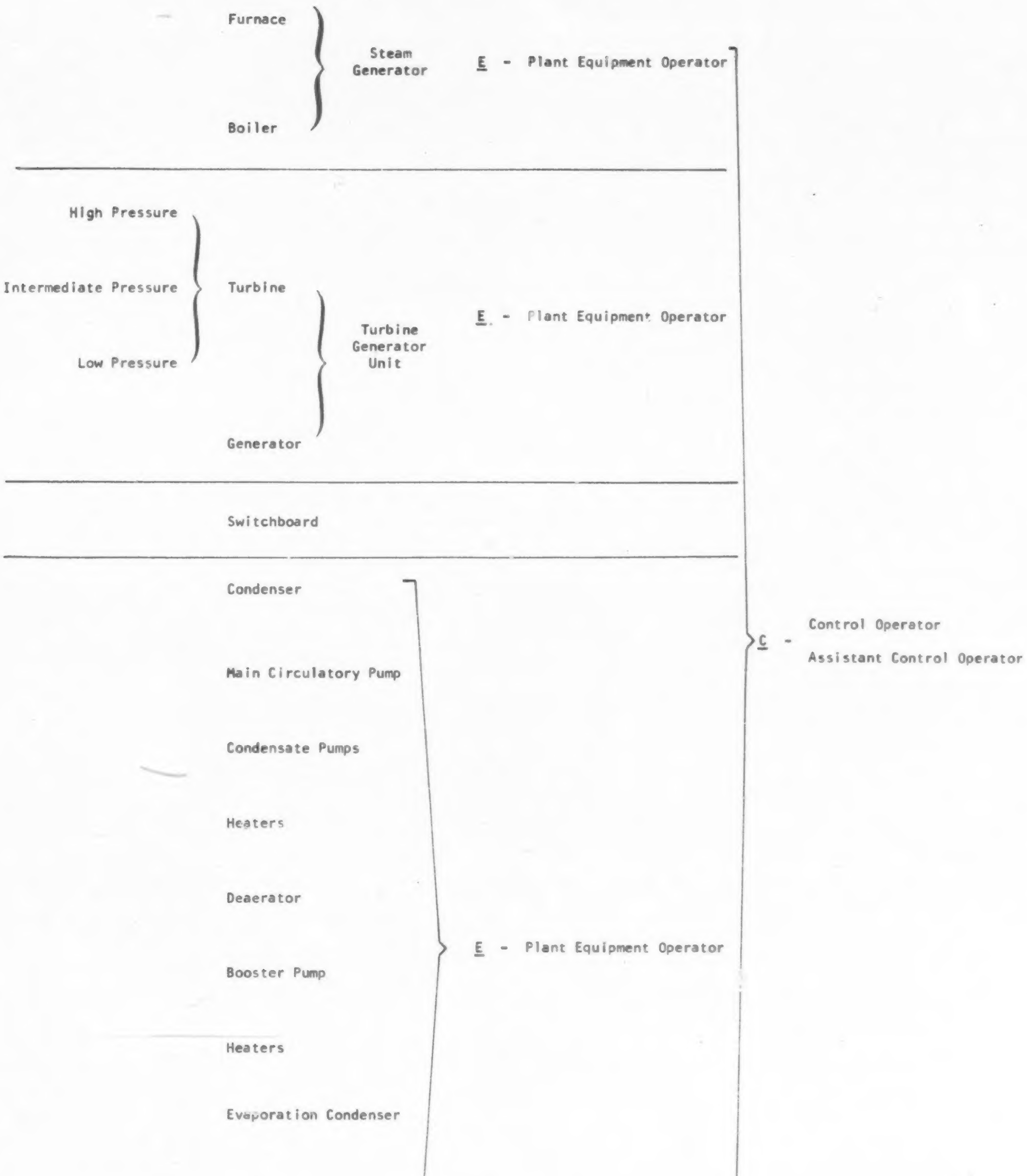
[1] The Plant has seven Steam Generators feeding into common header, which in turn feeds four Turbine-Generators.

[2] Control Locations: E - Plant Equipment Itself
C - Control Panels in Central Control Room (Centralized)

FIGURE C-8: POWER PLANT J2b - EQUIPMENT, CONTROL LOCATIONS AND OPERATORS

Simplified Process Flow Diagram


Fuel Air
Burn Fuel
Exhaust
Heat
Reheat
Superheat
Preheat
"Economizer"
Operate Turbine
Mech. Energy
Operate Turbine
Mech. Energy
Operate Turbine
Mech. Energy
Operate Generator
Switch
POWER OUTPUT
Cooling Water Circuit
Condense Steam
Pump
Pump
Heat
Deaerate
Pump
Heat
Condense Steam
Heat
Pump
Heat
Feedwater and Steam Flow

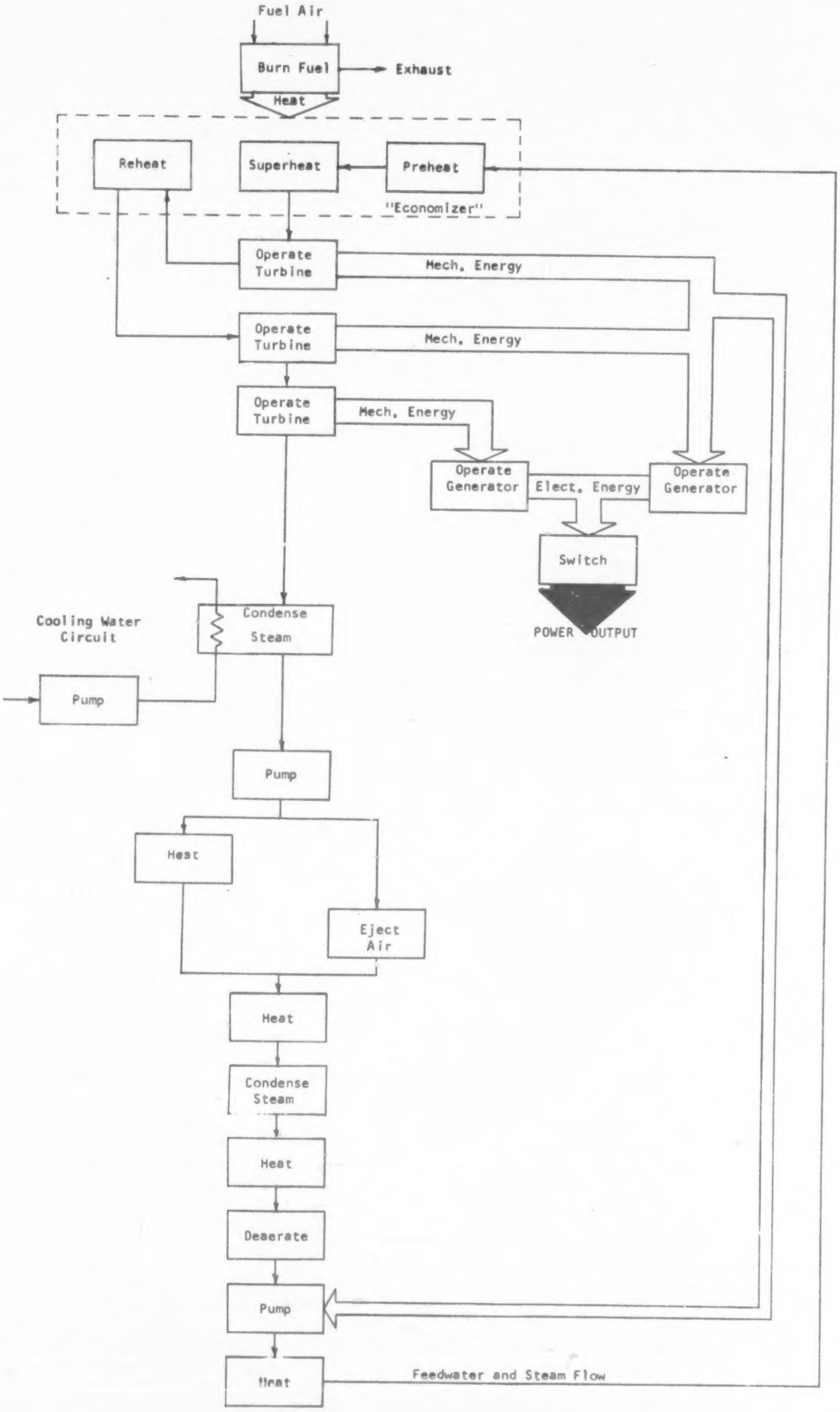

Furnace
Boiler
Steam Generator
E - Plant Equipment Operator
High Pressure
Intermediate Pressure
Low Pressure
Turbine
Generator
Turbine Generator Unit
E - Plant Equipment Operator
Switchboard
Condenser
Main Circulatory Pump
Condensate Pumps
Heaters
Deaerator
Booster Pump
Heaters
Evaporation Condenser
Heaters
Boiler Feed Pump
Heaters
E - Plant Equipment Operator
C - Control Operator
Assistant Control Operator

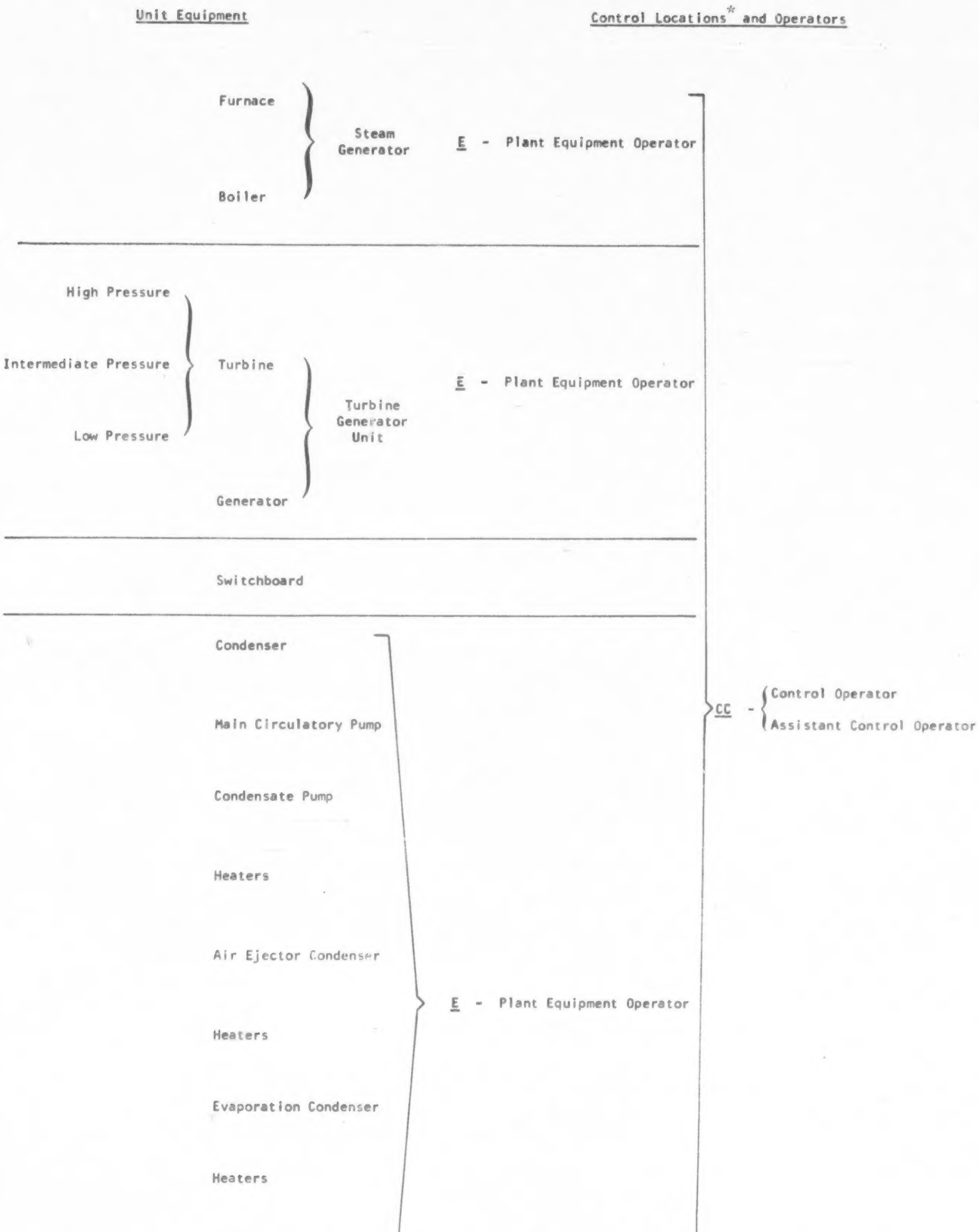
---

*Control Locations: E - Plant Equipment Itself; C - Control Panels in Central Control Room (Centralized)

FIGURE C-9: POWER PLANT J3 - EQUIPMENT, CONTROL LOCATIONS AND OPERATORS

Simplified Process Flow Diagram


Fuel Air
Burn Fuel
Exhaust
Heat
Reheat
Superheat
Preheat
"Economizer"
Operate Turbine
Mech. Energy
Operate Turbine
Mech. Energy
Operate Turbine
Mech. Energy
Operate Generator
Elect. Energy
Operate Generator
Switch
POWER OUTPUT
Cooling Water Circuit
Condense Steam
Pump
Pump
Heat
Eject Air
Heat
Condense Steam
Heat
Deaerate
Pump
Heat
Feedwater and Steam Flow

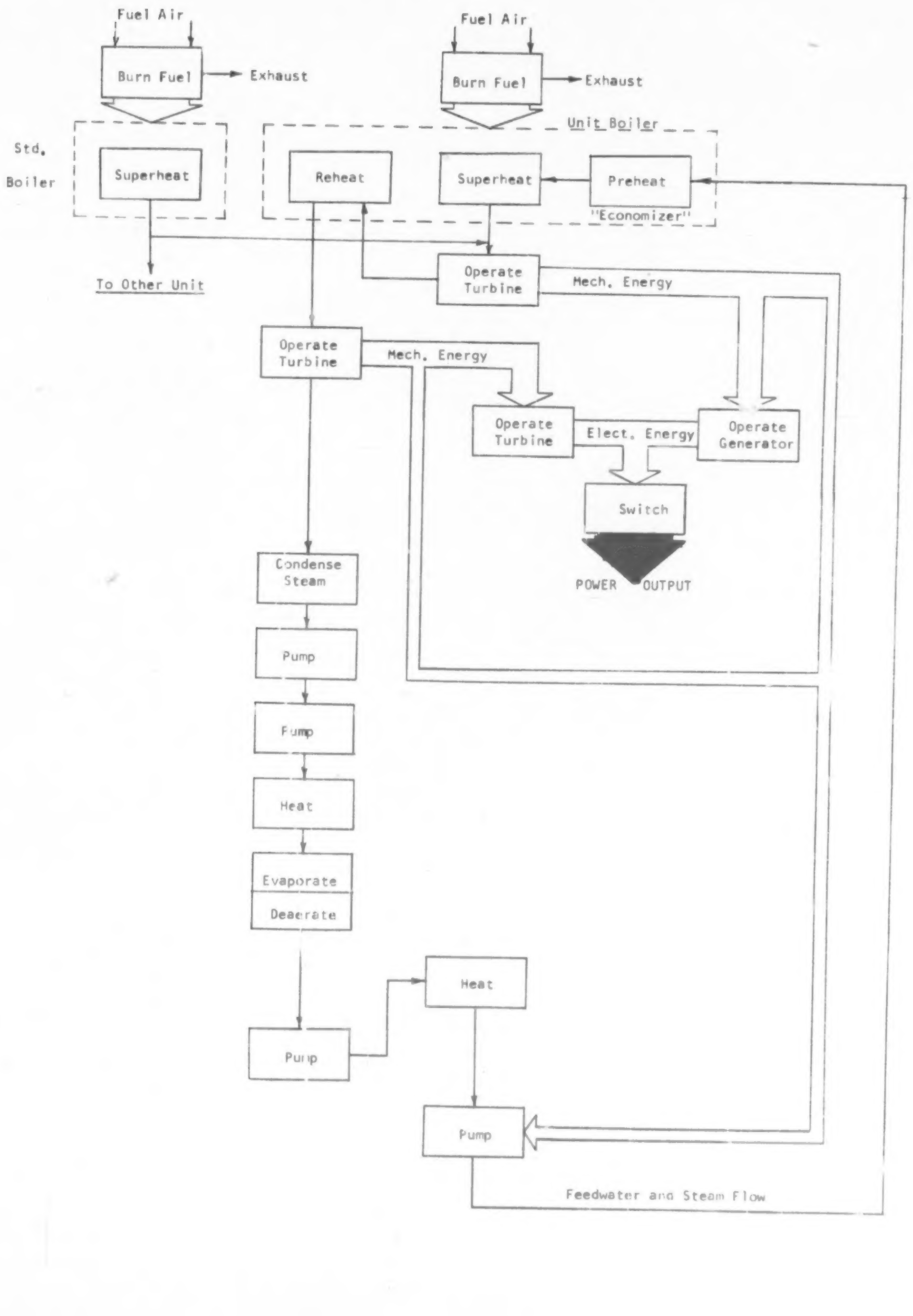

Unit Equipment
Control Locations* and Operators
Furnace
Boiler
Steam Generator
E - Plant Equipment Operator
High Pressure
Intermediate Pressure
Low Pressure
Turbine
Generator
Turbine Generator Unit
E - Plant Equipment Operator
Switchboard
Condenser
Main Circulatory Pump
Condensate Pump
Heaters
Air Ejector Condenser
Heaters
Evaporation Condenser
Heaters
Deaerator
Boiler Feed Pump
Heaters
E - Plant Equipment Operator
CC - Control Operator
Assistant Control Operator

---

*Control Locations: E - Plant Equipment Itself; CC - Control Panels and Computer in Central Control Room

FIGURE C-10: POWER PLANT K1 - EQUIPMENT, CONTROL LOCATIONS AND OPERATORS

Simplified Process Flow Diagram


Fuel Air
Burn Fuel
Exhaust
Std. Boiler
Superheat
To Other Unit
Fuel Air
Burn Fuel
Exhaust
Unit Boiler
Reheat
Superheat
Preheat
"Economizer"
Operate Turbine
Mech. Energy
Operate Turbine
Mech. Energy
Operate Turbine
Elect. Energy
Operate Generator
Switch
POWER OUTPUT
Condense Steam
Pump
Pump
Heat
Evaporate
Deaerate
Pump
Heat
Pump
Feedwater and Steam Flow

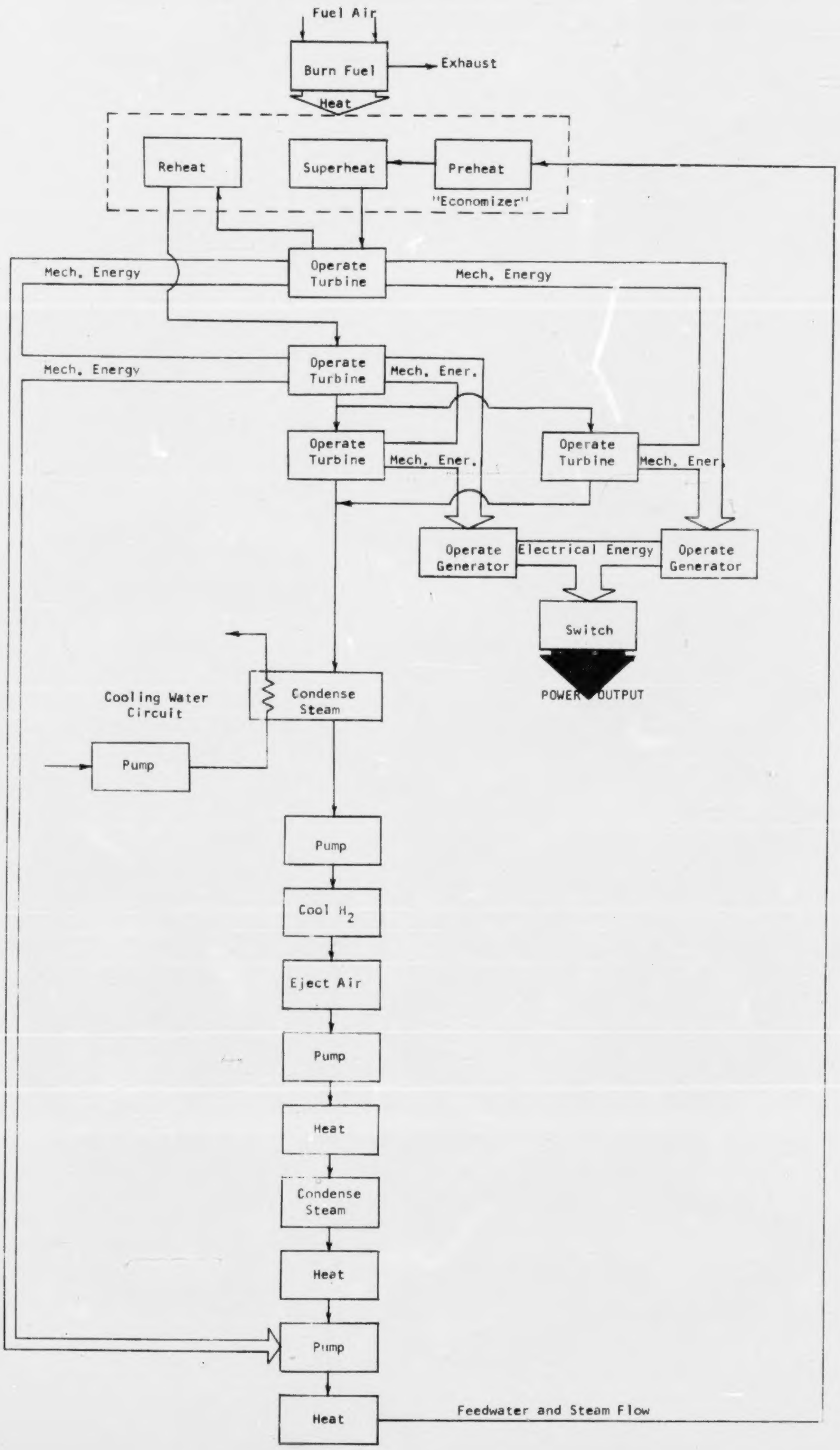
Unit Equipment			Control Locations[*2] and Operators		
	Furnaces Boilers	Steam[*1] Generators	**E** ---------------------- **N** (3 Control Panels, 1 for each Turbine-Generator) ---	H.P. Fireman	**E** - Shift Helper
High Pressure Low Pressure	Turbine Generator	Turbine Generator Unit	**E** --------------------- **N** (2 Control Panels, 1 for each Turbine-Generator) --	Turbine Tender	
	Switchboard		**C** --------------	1st Operator (Switching)	
	Condenser				
	Condensate Pump				
	Steam Jet Pump		**E** ----------------------	Oiler H.P. Fireman	
	Heater				
	Evaporator				
	Deaerator				
	Heaters				
	Primary Boiler Feed Pump Secondary Boiler Feed Pump		**E** --------------------- **N** ([illegible] Control Panels, 1 for each Turbine-Generator) --	Boiler Feedpumpman	

[*1] The Plant utilizes three Steam Generators, one for each Turbine-Generator and one Standard Steam Generator which feeds both Turbine-Generators.

[*2] Control Locations:
E - Plant Equipment Itself
N - Control Panel in Equipment Area (Non-Centralized)
C - Control Panel in Central Control Room (Centralized).

FIGURE C-11: POWER PLANT K2 - EQUIPMENT, CONTROL LOCATIONS AND OPERATORS

Simplified Process Flow Diagram


Fuel Air
Burn Fuel
Exhaust
Heat
Reheat
Superheat
Preheat
"Economizer"
Mech. Energy
Operate Turbine
Mech. Energy
Operate Turbine
Mech. Energy
Mech. Ener.
Operate Turbine
Mech. Ener.
Operate Turbine
Mech. Ener.
Operate Generator
Electrical Energy
Operate Generator
Switch
POWER OUTPUT
Cooling Water Circuit
Condense Steam
Pump
Pump
Cool H_2
Eject Air
Pump
Heat
Condense Steam
Heat
Pump
Heat
Feedwater and Steam Flow

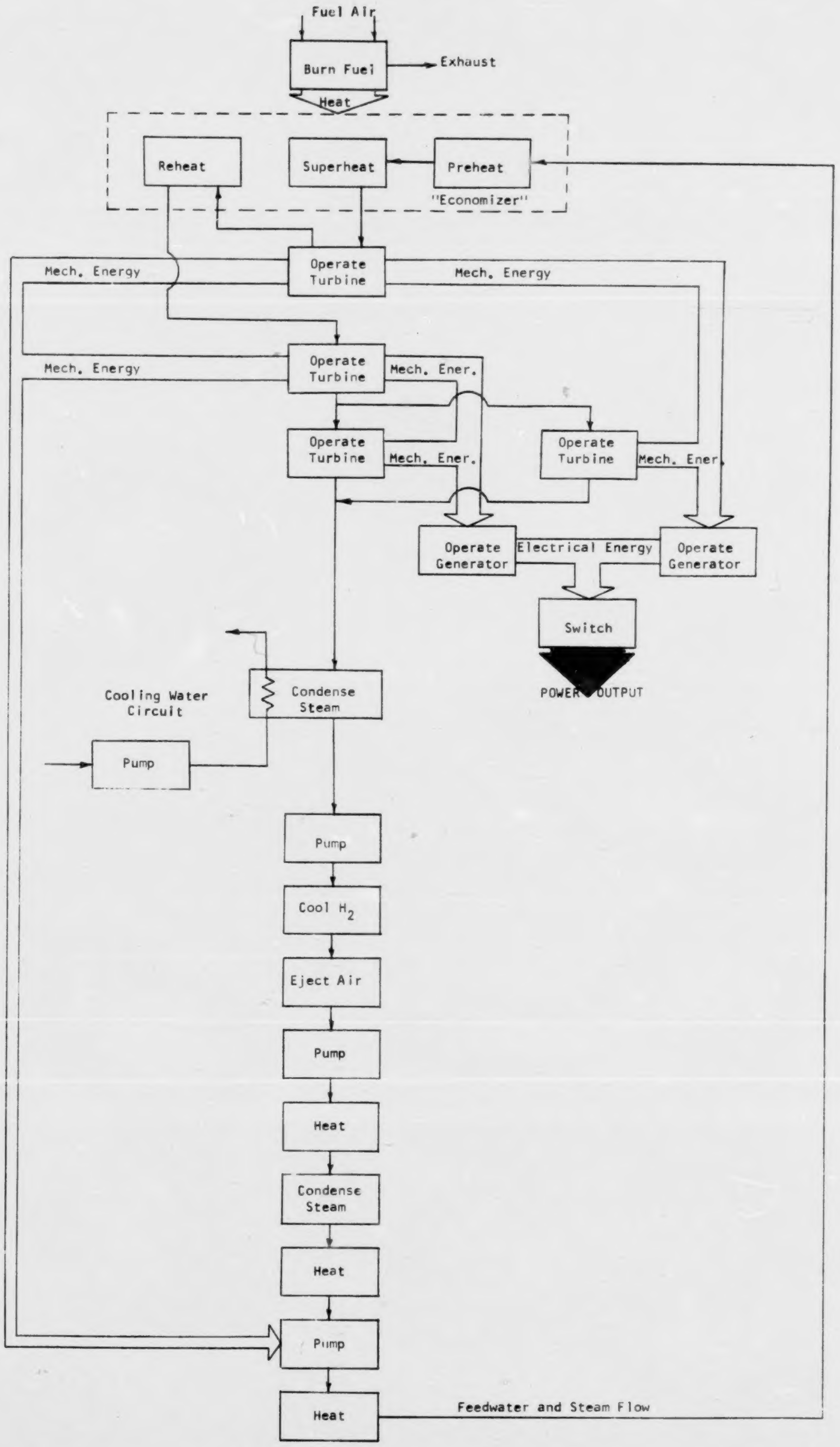
Unit Equipment			Control Locations* and Operators	
Furnace Boiler	Steam Generator		**E** - Assistant Control Operator	**C** - Sr. Control Operator Control Operator
High Pressure Intermediate Pressure Low Pressure	Turbine	Turbine Generator Unit	**E** - Assistant Control Operator	
	Generator			
Switchboard				
Condenser Main Circulatory Pump Condensate Pump Hydrogen Cooler Air Ejector Condenser Booster Pump Heaters Evaporation Condenser Heaters Boiler Feed Pump Heaters			**E** - Auxiliary Operator Oiler	

---

*Control Locations: **E** - Plant Equipment Itself; **C** - Control Panels in Central Control Room (Centralized)

FIGURE C-12: POWER PLANT K3 - EQUIPMENT, CONTROL LOCATIONS AND OPERATORS

Simplified Process Flow Diagram


Fuel
Air
Burn Fuel
Exhaust
Heat
Reheat
Superheat
Preheat
"Economizer"
Mech. Energy
Operate Turbine
Mech. Energy
Operate Turbine
Mech. Energy
Mech. Ener.
Operate Turbine
Mech. Ener.
Operate Turbine
Mech. Ener.
Operate Generator
Electrical Energy
Operate Generator
Switch
POWER OUTPUT
Cooling Water Circuit
Condense Steam
Pump
Pump
Cool H_2
Eject Air
Pump
Heat
Condense Steam
Heat
Pump
Heat
Feedwater and Steam Flow

Unit Equipment			Control Locations* and Operators	
Furnace	Steam Generator		E - Assistant Control Operator	CC - Senior Control Operator Control Operator
Boiler				
High Pressure	Turbine	Turbine Generator Unit	E - Assistant Control Operator	
Intermediate Pressure				
Low Pressure				
	Generator			
	Switchboard			
	Condenser		E - Auxiliary Operator Oiler	
	Main Circulatory Pump			
	Condensate Pump			
	Hydrogen Cooler			
	Air Ejector Condenser			
	Booster Pump			
	Heaters			
	Evaporation Condenser			
	Heaters			
	Boiler Feed Pump			
	Heaters			

---

*Control Locations: E - Plant Equipment Itself; CC - Control Panels and Computer in Central Control Room

3. METHOD OF DERIVING SKILL LEVEL VALUES FROM JOB EVALUATION SCHEMES

Electric Utility J

The job evaluation plan has been in operation for many years and did not change when control centralization and/or computerization was introduced. It is conceived in terms of the following factors each of which corresponds to a range of "points":

SCHOLASTIC CONTENT
TRAINING AND EXPERIENCE
Planning (Responsibility)
Seriousness of Errors
Hazard to Others
Physical Effort
Working Conditions
Personal Hazards
Irregular Hours
Supervision of Work

Only the first two factors were considered in the present study.

Scholastic content is defined as "a measure of that type of knowledge and technical skill which is usually acquired through academic training. While such knowledge and ability may be learned by other means than formal schooling, it normally is not learned advantageously on the job and should be acquired before assignment to the job requiring such information and training." It carries point values based on five discrete degrees:

Degree (1)	Job requires reading and writing of numbers and ordinary sentences such as used on employee forms and receipts for material.	10 pts
(2)	Job requires use of arithmetic such as multiplication and division; comprehension of written material such as instructions for a given work assignment or of single line drawings or construction sketches; the interpretation of readings from simple gages and meters; or knowledge of a similar level.	20 pts
(3)	Job requires the use of shop mathematics; interpretation of detailed blueprints and diagrams, or written instructions covering a complete procedure; or knowledge of a similar level.	40 pts
(4)	Job requires the use of mathematics such as algebra or geometry; use of the elementary principles of a	

basic science such as physics or chemistry at a similar level; or knowledge of a similar level. 70 pts

(5) Job requires selection of mathematical procedures, using algebra, geometry, or trigonometry, to solve varied problems; a knowledge of the applied theory of a basic science or of engineering practice; the preparation of detailed written instructions covering a complete procedure, drafting of equipment installations and modifications; or knowledge of a similar level. 110 pts

Training and experience is defined as a measure of the relative level of training and experience required for the successful execution of a job. The level is determined by ranking the jobs, considering such characteristics as the variety and complexity of the problems encountered, procedures followed, material and tools used, equipment operated or maintained, and the practical knowledge and skill involved in each job. After the ranking process, the jobs of a similar level are grouped and points allocated according to the scale shown below.

Degree:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Points:	28	56	84	112	140	168	196	224	252	280	308	336	364	392	420

The Scholastic Content and Training and Experience scores allocated to each job were summed to yield the total skill score used in the analysis.

Electric Utility K

Electric Utility K does not have a job evaluation scheme. Instead all jobs are rated relative to each other in a "line of progression" based on company "job definitions." To allow a comparison of the skill profiles of the two electric utilities, the "skill scores" for all jobs in Electric Utility K were evaluated on the Electric Utility J Evaluation Plan. This evaluation was done by the researchers with assistance from Electric Utility K personnel.

4. RAW DATA USED FOR THE DEVELOPMENT OF SKILL PROFILES

These data are tabulated under the title of each technological level. The following notes explain the meaning of each column in the table:

Job Code:	The codes are internal codes, assigned to each job to facilitate cross-referencing. The letter (J) identifies the utility, the attached figure identifies the technology and the figure separated by a dash, the job. The letter "a" or "b" attached to technology level 2 differentiates two power plants of different physical size at the same technology level. The letter "m" or "s" attached to the job number indicates respectively a maintenance or supervisory job.
Job D.O.T. Number:	These six digit numbers are taken from the 1965 edition of the Dictionary of Occupational Titles. The matching of D.O.T. number and job was done by the researchers on the basis of job descriptions and their own knowledge of the jobs.
Job Title:	Official titles assigned to the jobs by the firms.
Skill Level:	Skill factor totals were supplied by Firm J for all operating and maintenance jobs and are based on the firm's evaluation plan described in Section 3 of this Appendix. This plan was also used by the researchers to estimate the skill factor points for supervisory personnel.
Manhours:	All manhours are given per 8 hour shift. As plant maintenance and supervision work an eight hour shift five days a week, while the plant runs continuously for 24 hours a day, the manhours for each maintenance man and supervisor were averaged over 168 hours. For Divisional Maintenance the 20 to 35 shifts spent on actual overhaul were prorated over the period from the start of one overhaul to the start of the next. Dividing the figures shown by 8 yields manhours per plant operating hour. To obtain manhours per unit output (10^6kwhrs) these have to be further divided by plant capacity in kilowatts and multiplied by 10^6.

OPERATING CREWS

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
J2 Non-Centralized Control				
J1-1	952.782	2nd Auxiliary Operator	180	16
J1-2	952.782	1st Auxiliary Operator	264	16
J1-3	951.885	Boiler Operator	264	16
J1-4	952.782	Turbine Operator	264	8
J1-5	951.885	1st Boiler Operator	292	8
J1-6	952.782	1st Turbine Operator	292	8
J1-7	952.782	Switchboard Operator - Steam	406	8
J2a Centralized Control				
J2a-1	952.782	Plant Equipment Operator	320	24
J2a-2	952.782	Assistant Control Operator	406	9.9*
J2a-3	952.782	Control Operator	462	8
J2b Centralized Control				
J2b-1	952.782	Plant Equipment Operator	320	16
J2b-2	952.782	Assistant Control Operator	406	8
J2b-3	952.782	Control Operator	462	8
J3b Centralized/Computerized Control				
J3-1	952.782	Plant Equipment Operator	320	16**
J3-2	952.782	Assistant Control Operator	406	8
J3-3	952.782	Control Operator	462	8

---

* This is an average value. There are two A.C.O.'s on dayshift Monday through Friday. At all other times, including evenings and weekends, there is one A.C.O.

** In actuality there is only one Plant Equipment Operator assigned to this plant per shift. A second Plant Equipment Operator divides his time between this plant and a second adjacent plant. If this time-sharing possibility did not exist, two Plant Equipment Operators would be required per shift.

OPERATING CREWS

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
K1 Non-Centralized Control				
K1-1	952.782	Shift Helper	96	16
K1-2	952.782	Oiler	180	16
K1-3	951.885	H.P. Fireman	264	24
K1-4	952.782	Boiler Feedpumpman	264	8
K1-5	952.782	Turbine Tender	292	8
K1-6	952.782	1st Operator (Switching)	406	2*
K2 Centralized Control				
K3 Centralized/Computerized Control				
K2-1 K3-1	952.782	Oiler	180	4
K2-2 K3-2	952.782	Auxiliary Operator	320	8
K2-3 K3-3	952.782	Assistant Control Operator	406	8
K2-4 K3-4	952.782	Control Operator	462	8
K2-5 K3-5	952.782	Senior Control Operator	462	8

---

*The 1st Operator (Switching) performs various system electrical switching operations. It is estimated by Firm K that he uses $\frac{1}{4}$ of his time performing switching operations for this plant.

5. LENGTH OF OPERATORS' GENERAL EDUCATION AND ON-THE-JOB EXPERIENCE

The internal job codes and job titles used in Section 4 are retained to facilitate cross-referencing.

Estimates of general educational requirements were made by researchers. Estimates of on-the-job requirements were made by Firm J for all J2a, J2b, and J3 jobs. Estimates for K1, K2 and K3 were made by researchers.

Job Code	Job Title	Estimated Required General Education (Years of High School)			Estimated Required On-the-Job Experience (Months)				
		0	1-2	3-4	0-11	12-23	24-53	54-77	78-114
J1	NON-CENTRALIZED								
J1-1	2nd Auxiliary Operator			X	X				
J1-2	1st Auxiliary Operator			X		X			
J1-3	Boiler Operator			X		X			
J1-4	Turbine Operator			X		X			
J1-5	1st Boiler Operator			X		X			
J1-6	1st Turbine Operator			X		X			
J1-7	Switchboard Operator - Steam			X				X	
J2a	CENTRALIZED								
J2b	CENTRALIZED								
J3	CENTRALIZED/COMPUTERIZED								
J2a-1 J2b-1 J3 -1	Plant Equipment Operator			X			X		
J2a-2 J2b-2 J3 -2	Assistant Control Operator			X				X	
J2a-3 J2b-3 J3 -3	Control Operator			X					X

TABLE C-1: ESTIMATED EDUCATIONAL AND JOB EXPERIENCE REQUIREMENTS, DIRECT LABOR ONLY, UTILITY J.

Job Code	Job Title	Estimated Required General Education (Years of High School)			Estimated Required On-the-Job Experience (Months)				
		0	1-2	3-4	0-11	12-23	24-53	54-77	78-114
K1	NON-CENTRALIZED								
K1-1	Shift Helper	X			X				
K1-2	Oiler			X	X				
K1-3	H.P. Fireman			X		X			
K1-4	Boiler Feedpumpman			X		X			
K1-5	Turbine Tender			X		X			
K1-6	1st Operator (Switching)			X				X	
K2	CENTRALIZED								
K3	CENTRALIZED/COMPUTERIZED								
K2-1 K3-1	Oiler			X	X				
K2-2 K3-2	Auxiliary Operator			X			X		
K2-3 K3-3	Assistant Control Operator			X				X	
K2-4 K3-4	Control Operator			X					X
K2-5 K3-5	Senior Control Operator			X					X

TABLE C-2: ESTIMATED EDUCATIONAL AND JOB EXPERIENCE REQUIREMENTS, DIRECT LABOR ONLY, UTILITY K.

6. ANALYSIS OF VARIANCE LAYOUT OF DATA AND DETAILED SUMMARY

Improved estimate of residual variance was obtained by pooling the sums of squares and the degrees of freedom of the original residual estimate and of the T x F interaction.

The mean squares of the SL x T and SL x F interactions and of the main effects were tested against this improved estimate.

Key to abbreviations:

D.F. - Degrees of Freedom
S.S. - Sum of Squares
M.S. - Mean Squares
V.R. - Variance Ratio
SL - Skill Levels
TL - Technology Levels
F - Firms (Utilities)

Skill Level	Technology Level 1		Technology Level 2	
	J1	K1	J2a	K2
Low	2.00	4.00	0.00	0.50
Medium	7.00	5.00	3.00	1.00
High	1.00	0.25	2.24	3.00
Totals	10.00	9.25	5.24	4.50

TABLE C-3: MANHOURS PER PLANT OPERATING HOUR CLASSIFIED BY SKILL LEVEL, FIRM AND TECHNOLOGY LEVEL.

Source of Variance	D.F.	S.S.	M.S.	V.R.	Significance Level
Between Skill Levels	2	15.06	7.53	19.92	$P < 0.025$
Between Technologies	1	7.54	7.54	19.94	$P < 0.025$
Between Firms	1	0.18	0.18	0.49	
SL x T	2	20.00	10.00	26.44	$P < 0.05$
SL x F	2	5.38	2.69	7.11	
T x F	1	0.00	0.00		
Residual	2	1.13	0.57		
Improved Residual Estimate	(3)	1.13	0.38		
Total	11	49.29			

TABLE C-4: ANALYSIS OF VARIANCE SUMMARY (PER PLANT OPERATING HOUR BASIS).

7. DERIVATION OF INDIRECT LABOR MANHOURS

To determine maintenance and supervision manhours different methods had to be adopted for the plant at TL1 and for the plants at higher technology levels, for the following reasons:

1. As shown in Figure 5.5, plant J1 like most of its generation was completely autonomous and self sufficient with respect to maintenance. All maintenance being in-plant, the manhours of each repairman could be treated exactly as if they were direct labor manhours. The three other plants are dependent on Divisional Maintenance created in 1952 and responsible for major overhaul work. Overhauls however occur at different intervals in different plants (usually every 3 or 4 years) and take from 4-7 weeks to complete, depending mainly on the age of the plant and the complexity of its equipment. Also, the size and the composition of the Divisional Maintenance squads dispatched to overhaul a plant is not always the same. All these factors were taken into account for manhour compilations.
2. Plant J1 was co-dimensional with the Power Generating station, and all of the manhours worked by each station (in-plant) repairman and maintenance supervisor could thus be prorated to unit output or plant operating hour. The three remaining plants J2a, J2b and J3 on the other hand are part of a two-plant station, and the manhours of the station maintenance force and also of some of the operating foremen are accordingly shared between them and their sister plants. Hence estimates had to be obtained of the ratios in which each supervisor and repairman apportions his effort between the two plants, and only the proportion of time spent on the plants studied was considered.

8. RAW DATA USED FOR SKILL PROFILES

MAINTENANCE

J1 NON-CENTRALIZED (Capacity: 300,000 kw)

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
J1-1m	899.381	Utilityman	38	7.62
J1-2m	821.887	Electrical Helper	94	5.71
J1-3m	821.887	Maintenance-Steam Helper	94	11.43
J1-4m	840.781	Painter, Steam Maintenance	272	11.43
J1-5m	631.281	Boiler and Condenser Mechanic	272	3.81
J1-6m	631.281	Maintenance Machinist	320	5.71
J1-7m	863.884 861.381	Brick and Asbestos Man	320	1.90
J1-8m	820.281 829.281	Electrician	350	3.81
J1-9m	812.884	Welder - Steam	378	1.90
J1-10m	820.281 829.281	Shift Electrician	406	11.43
J1-11m	710.281	Instrument Repairman	446	7.62
J1-12m	729.684	Test A Technician	502	1.90

J2a CENTRALIZED (Capacity: 300,000 kw)

In-Plant Maintenance Group

Plant Maintenance

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
J2a-1m	899.381	Utilityman	38	4.76
J2a-2m	821.887	Maintenance-Steam Helper	94	11.43
J2a-3m	840.781	Painter, Steam Maintenance	272	5.72
J2a-4m	631.281	Boiler and Condenser Mechanic	272	8.58
J2a-5m	631.281	Maintenance Machinist	320	5.72
J2a-6m	863.884 861.381	Brick and Asbestos Man	320	2.86
J2a-7m	820.281 829.281	Electrician	350	3.81
J2a-8m	812.884	Welder - Steam	378	1.43

Instrument Maintenance

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
J2a-9m	710.281	Apprentice Instrument Repairman	350	5.72
J2a-10m	710.281	Instrument Repairman	446	4.76
J2a-11m	729.684	Test A Technician	502	0.95

MAINTENANCE

J2a CENTRALIZED (Cont'd.)

Division Maintenance Group (Overhaul Crew)

Total overhaul time per Turbine-Generator and associated Boiler(s) per 3 year period: 84 shifts

Additional time of Boiler and Condenser Crew to inspect and repair Boilers per 3 year period: 10 shifts

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
Mechanical Crew				
J2a-12m	631.884	Maintenance Machinist, Helper	94	1.37
J2a-13m	631.281	Apprentice Maintenance Machinist	292	0.59
J2a-14m	631.281	Maintenance Machinist	320	3.13
Electrical Crew				
J2a-15m	821.887	Electrical Helper	94	0.20
J2a-16m	820.281	Apprentice Electrician	322	0.20
J2a-17m	820.281 829.281	Electrician	350	0.78
J2a-18m	729.684	Test Technician	446	0.10
Boiler and Condenser Crew				
J2a-19m	631.884	Boiler and Condenser Helper	94	0.29
J2a-20m	631.281	Boiler and Condenser Mechanic	272	1.17
J2a-21m	863.884 861.381	Brick and Asbestos Man	320	0.15
J2a-22m	812.884	Welder - Steam	378	0.29

MAINTENANCE

J2b CENTRALIZED (Capacity: 350,000 kw)

In-Plant Maintenance Group

Plant Maintenance

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
J2b-1m	899.381	Utilityman	38	4.76
J2b-2m	821.887	Maintenance-Steam Helper	94	3.81
J2b-3m	840.781	Painter, Steam Maintenance	272	1.90
J2b-4m	631.281	Boiler and Condenser Mechanic	272	2.85
J2b-5m	631.281	Maintenance Machinist	320	1.90
J2b-6m	863.884 861.381	Brick and Asbestos Man	320	0.95
J2b-7m	820.281 829.281	Electrician	350	3.81
J2b-8m	829.281	Welder - Steam	378	0.48

Instrument Maintenance

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
J2b-9m	710.281	Apprentice Instrument Repairman	350	5.72
J2b-10m	710.281	Instrument Repairman	446	4.76
J2b-11m	729.684	Test A Technician	502	0.95

Division Maintenance Group (Overhaul Crew)

Total overhaul time per Boiler-Turbine-Generator unit per 4 year period:	105 shifts
Additional time of Boiler and Condenser Crew to inspect and repair Boiler(s) per 4 year period:	5 shifts

Mechanical Crew

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
J2b-12m	631.884	Maintenance Machinist, Helper	94	0.73
J2b-13m	631.281	Apprentice Maintenance Machinist	292	0.37
J2b-14m	631.281	Maintenance Machinist	320	1.65

MAINTENANCE

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
J2b CENTRALIZED (Cont'd.)				
Division Maintenance Group (Cont'd.)				
Electrical Crew				
J2b-15m	821.887	Electrical Helper	94	0.09
J2b-16m	820.281	Apprentice Electrician	322	0.09
J2b-17m	820.281 829.281	Electrician	350	0.27
J2b-18m	729.684	Test Technician	446	0.09
Boiler and Condenser Crew				
J2b-19m	631.884	Boiler and Condenser Helper	94	0.66
J2b-20m	631.281	Boiler and Condenser Mechanic	272	0.88
J2b-21m	863.884 861.381	Brick and Asbestos Man	320	0.22
J2b-22m	812.884	Welder - Steam	378	0.22
J3 CENTRALIZED/COMPUTERIZED (Capacity: 640,000 kw)				
In-Plant Maintenance Group				
Plant Maintenance				
J3-1m	899.381	Utilityman	38	1.91
J3-2m	821.887	Maintenance-Steam Helper	94	8.00
J3-3m	840.781	Steam Maintenance Painter	272	1.91
J3-4m	631.281	Boiler and Condenser Mechanic	272	4.19
J3-5m	631.281	Maintenance Machinist	320	2.86
J3-6m	820.281 829.281	Electrician	350	3.71
J3-7m	812.884	Welder - Steam	378	0.95
Instrument Maintenance				
J3-8m	710.281	Apprentice Instrument Repairman	350	1.91
J3-9m	710.281 003.281	Instrument Technician	474	4.57
J3-10m	729.684	Test A Technician	502	1.91

MAINTENANCE

J3 CENTRALIZED/COMPUTERIZED (Cont'd.)

Division Maintenance Group (Overhaul Crew)

Total overhaul time per Boiler-Turbine-Generator unit per 3 year period: 126 shifts

Additional time of Boiler and Condenser Crew to inspect and repair Boiler(s) per 3 year period: 5 shifts

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
Mechanical Crew				
J3-11m	631.884	Maintenance Machinist Helper	94	2.20
J3-12m	631.281	Apprentice Maintenance Machinist	282	0.59
J3-13m	631.281	Maintenance Machinist	320	3.66
Electrical Crew				
J3-14m	821.887	Electrical Helper	94	0.29
J3-15m	820.281	Apprentice Electrician	322	0.15
J3-16m	820.281 829.281	Electrician	350	0.73
J3-17m	729.684	Test Technician	446	0.29
Boiler and Condenser Crew				
J3-18m	631.884	Boiler and Condenser Helper	94	2.56
J3-19m	631.281	Boiler and Condenser Mechanic	272	1.71
J3-20m	863.884 861.381	Brick and Asbestos Man	320	0.51
J3-21m	812.884	Welder - Steam	378	0.34

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SUPERVISION

Job Code	Job Title	Skill Level	Manhours Per Shift
J1 NON-CENTRALIZED	(Capacity: 300,000 kw) - Supervision		
In-Plant Group			
Operations			
J1-1s	Head Boiler Operator	434	8.00
J1-2s	Head Turbine Operator	434	8.00
J1-4s	Watch Engineer	490	8.00
J1-5s	Assistant Station Chief	530	0.95
Plant Maintenance			
J1-6s	Steam Maintenance Foreman	462	1.90

J2a CENTRALIZED (Capacity: 300,000 kw) - Supervision

J2b CENTRALIZED (Capacity: 350,000 kw) - Supervision

			J2a	J2b
In-Plant Group				
Operations				
J2-3s	Operating Foreman	462	2.67	2.67
J2-4s	Watch Engineer	490	5.33	5.33
J2-5s	Supervisor of Plant Operations	530	0.95	0.95
Plant Maintenance				
J2-6s	Steam Maintenance Foreman	462	1.90	1.90
J2-7s	Supervisor of Plant Maintenance	490	0.95	0.95
Instrument Maintenance				
J2-8s	Instrument Foreman, Maintenance	462	0.95	0.95
Division Maintenance Group				
J2-10s	Sub-Foreman, Steam Maintenance (Boiler and Condenser)	462	0.08	0.11
J2-11s	Sub-Foreman, Steam Maintenance (Electrical)	462	0.05	0.05

SUPERVISION

J2 CENTRALIZED (Cont'd.)

Division Maintenance Group

Job Code	Job Title	Skill Level	Manhours Per Shift	
			J2a	J2b
J2-12s	Sub-Foreman, Steam Maintenance (Mechanical)	462	0.15	0.14
J2-13s	Foreman, Mechanical Maintenance	490	0.05	0.05
J2-14s	Foreman, General, Electrical and Boiler	530	0.05	0.05

J3 CENTRALIZED/COMPUTERIZED (Capacity: 600,000 kw) - Supervision

In-Plant Group

Operations

Job Code	Job Title	Skill Level	Manhours Per Shift
J3-3s	Operating Foreman	462	1.90
J3-4s	Watch Engineer	490	6.10
J3-5s	Supervisor of Plant Operations	530	0.95

Plant Maintenance

Job Code	Job Title	Skill Level	Manhours Per Shift
J3-6s	Maintenance Foreman, Steam	464	0.95
J3-7s	Supervisor of Plant Maintenance	490	0.95

Instrument Maintenance

Job Code	Job Title	Skill Level	Manhours Per Shift
J3-8s	Instrument Foreman, Maintenance	464	0.95
J3-9s	Supervisor of Instrumentation	502	0.95

Division Maintenance Group

Job Code	Job Title	Skill Level	Manhours Per Shift
J3-10s	Sub-Foreman, Steam Maintenance (Boiler and Condenser)	462	0.17
J3-11s	Sub-Foreman, Steam Maintenance (Electrical)	462	0.08
J3-12s	Sub-Foreman, Steam Maintenance (Mechanical)	462	0.23
J3-13s	Foreman, Mechanical Maintenance	490	0.08
J3-14s	Foreman, General, Electrical and Boiler	530	0.08

9. SKILL DISTRIBUTIONS AND SKILL PROFILES -- MAINTENANCE LABOR ONLY

In each pair of Tables and Figures the first shows the maintenance labor manhours by skill level on a per unit output basis, the second of these same the manhours on a per plant operating hour basis.

TABLE C-5: MAINTENANCE LABOR FORCE SKILL DISTRIBUTIONS FOR NON-CENTRALLY (TL1) AND CENTRALLY (TL2) CONTROLLED POWER PLANTS IN UTILITY J.

(a) Basis: 10^6 Kwhr

Organization: Electric Utility J

Process: Power Production by Steam-Electric Process

Technology (Level 1): Non-Centralized Control

Technology (Level 2): Centralized Control

Source of Data: Direct Observation and Firms Records

Period: 1950-1952 (TL1) and 1964-1967 (TL2)

1		2	3	4	5	6	7	8	9	10	11
Skill Level		Skill Point Range	Manhours Per 10^6 kwhr			Manhours as % of Total for Technology Level			Number of Job Types		
			TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High	6										
	5	449-530	0.8	0.4	- 0.4	2.6	1.5	- 1.1	1	1	0
	4	367-448	8.7	2.7	- 6.0	28.1	10.1	-18.0	3	3	0
Medium	3	285-366	4.8	9.6	+ 4.8	15.5	36.1	+20.6	3	6	+ 3
	2	203-284	6.4	6.4	0.0	20.6	24.1	+ 3.5	2	2	0
Low	1	121-203	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	0	38-120	10.3	7.5	- 2.8	33.2	28.3	- 5.0	3	5	+ 2
		Totals	31.0	26.6	- 4.4	100.0	100.0	0.0	12	17	+ 5
		Net Manhour Change -14.2%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	262.9	144.6
Technology (Level 2)	258.9	123.6
Change	- 4.0	

(b) Basis: Plant Operating Hour

Organization: Electric Utility J

Process: Power Production by Steam-Electric Process

Technology (Level 1): Non-Centralized Control

Technology (Level 2): Centralized Control

Source of Data: Direct Observation and Firm's Records

Period: 1950-1952 (TL1) and 1964-1967 (TL2)

1	2	3	4	5	6	7	8	9	10	11
Skill Level	Skill Point Range	Manhours Per Plant Operating Hour			Manhours as % of Total for Technology Level			Number of Job Types		
		TL1	TL2	Change	TL1	TL2	Change	TL1	TL2	Change
High 6										
5	449-530	0.3	0.1	- 0.2	3.2	1.3	- 1.9	1	1	0
4	367-448	2.6	0.8	- 1.8	28.0	10.0	-18.0	3	3	0
Medium 3	285-366	1.4	2.9	+ 1.5	15.1	36.3	+21.2	3	6	+ 6
2	203-284	1.9	1.9	0.0	20.4	23.7	+ 3.3	2	2	0
Low 1	121-202	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0	38-120	3.1	2.3	- 0.8	33.3	28.7	- 4.6	3	5	+ 2
	Totals	9.3	8.0	- 1.3	100.0	100.0	0.0	12	17	+ 5
	Manhour Change Due to Technology Change -14.1%									

	Mean Skill Level	Standard Deviation
Technology (Level 1)	262.9	144.6
Technology (Level 2)	258.9	123.6
Change	- 4.0	

FIG. C-13: MAINTENANCE LABOR FORCE SKILL PROFILES FOR NON-CENTRALLY AND CENTRALLY CONTROLLED POWER PLANTS IN UTILITY J.

(a) Basis: 10^6 Kwhr

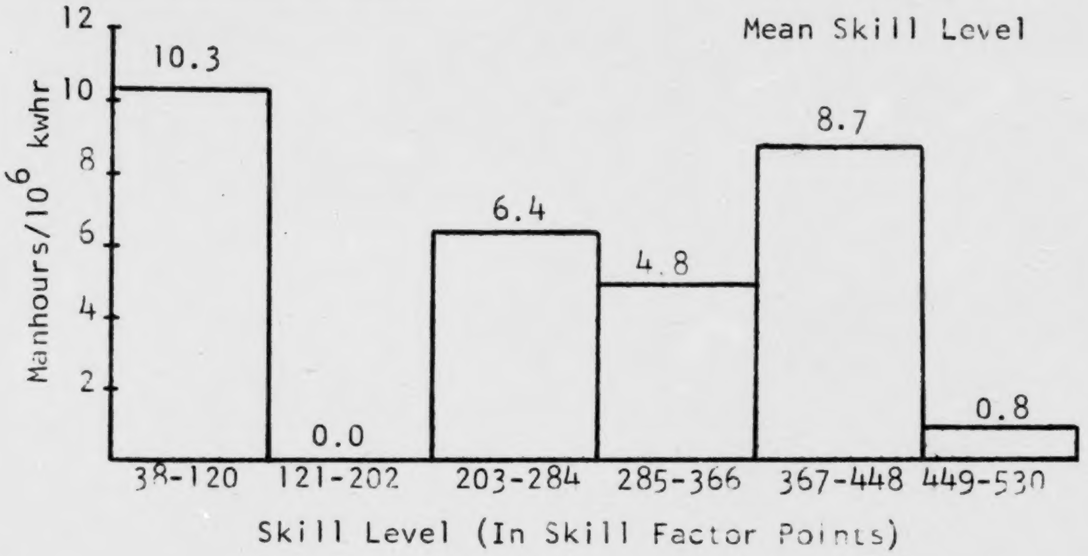
☐ In-Plant Maintenance

■ Division Maintenance

NON-CENTRALIZED CONTROL

Total Manhours/10^6 kwhr = 31.0

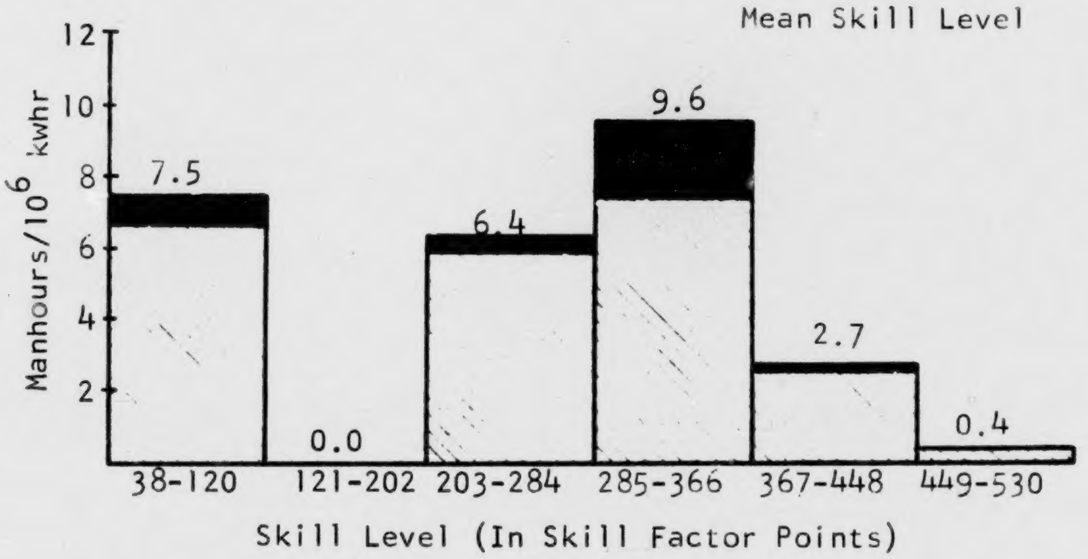
Mean Skill Level = 262.9



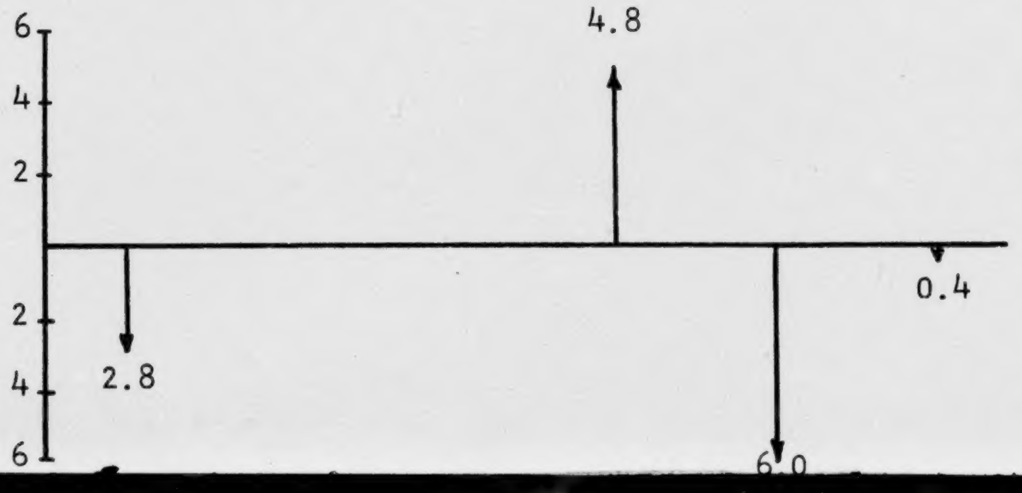
CENTRALIZED CONTROL

Total Manhours/10^6 kwhr = 26.6

Mean Skill Level = 258.9



CHANGES - OLD TO NEW TECHNOLOGY

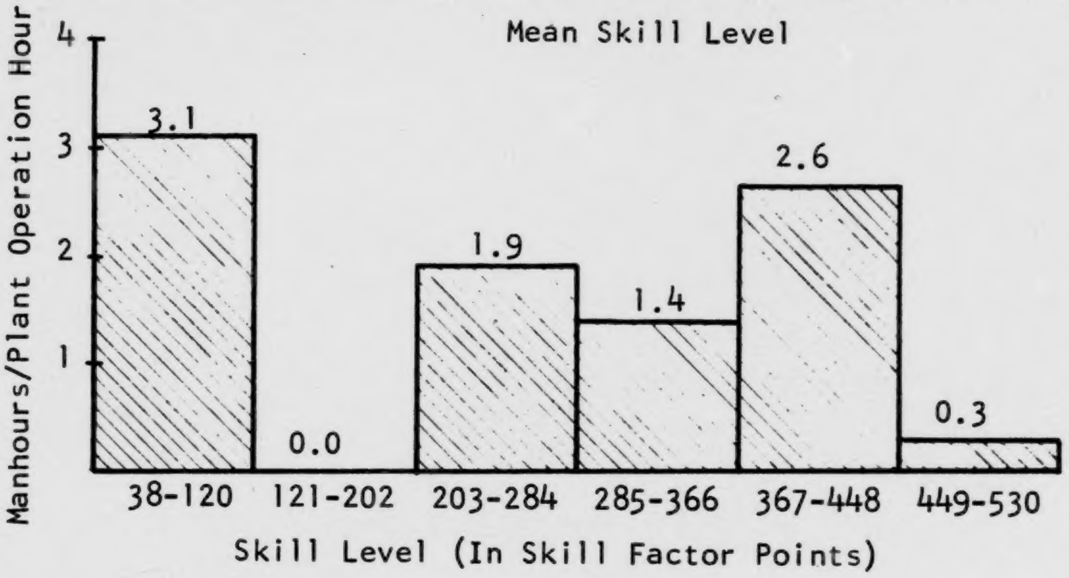


(b) Basis: Plant Operating Hour

▨ In-Plant Maintenance ■ Division Maintenace

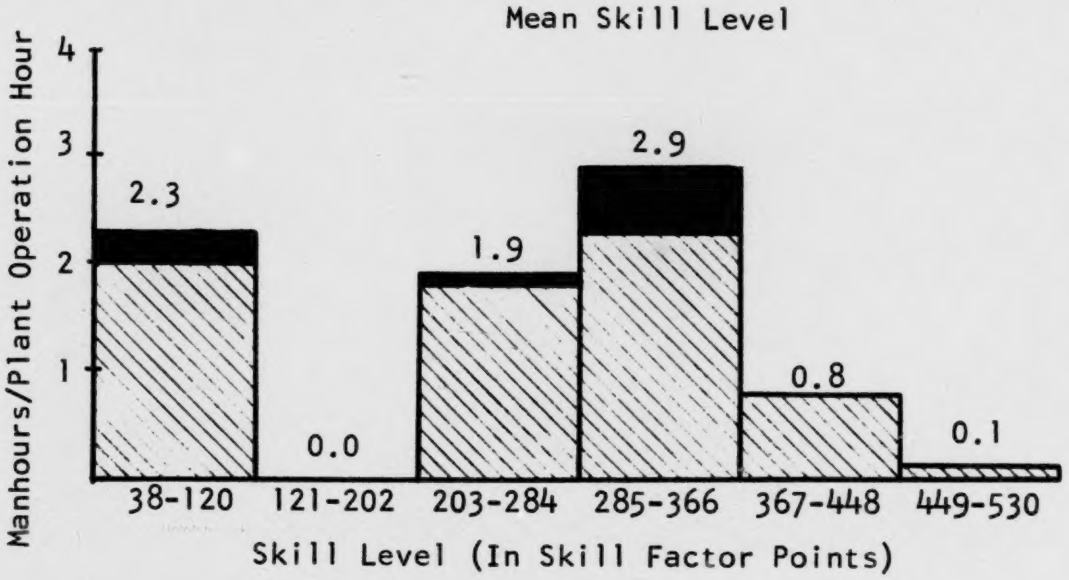
NON-CENTRALIZED CONTROL

Total Manhours/Plant Operation Hour = 9.3
Mean Skill Level = 262.9

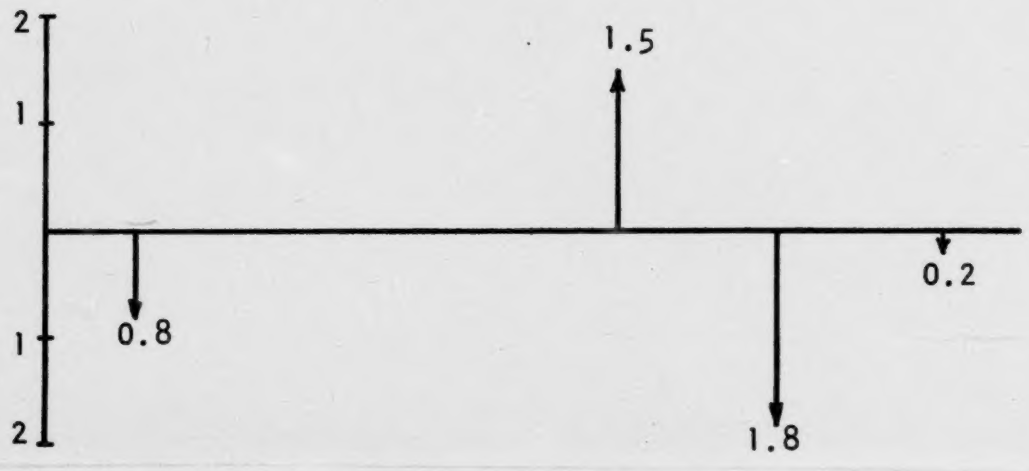


CENTRALIZED CONTROL

Total Manhours/Plant Operation Hour = 8.0
Mean Skill Level = 258.9



CHANGES - OLD TO NEW TECHNOLOGY



(a) Basis: 10^6 Kwhr

Organization: Electric Utility J

Process: Power Production by Steam-Electric Process

Technology (Level 2): Centralized Control

Technology (Level 3): Centralized/Computerized Control

Source of Data: Direct Observation and Firm's Records

Period: 1962-1966 (TL2) and 1964-1967 (TL3)

1		2	3	4	5	6	7	8	9	10	11
Skill Level		Skill Point Range	Manhours Per 10^6 kwhr			Manhours as % of Total for Technology Level			Number of Job Types		
			TL2	TL3	Change	TL2	TL3	Change	TL2	TL3	Change
High	6										
	5	449-530	0.3	1.3	+ 1.0	2.3	14.8	+12.5	1	2	+ 1
	4	367-448	2.0	0.3	- 1.7	15.0	3.4	-11.6	3	2	- 1
Medium	3	285-366	5.4	2.8	- 2.6	40.6	31.8	- 8.8	6	6	0
	2	203-284	2.0	1.5	- 0.5	15.0	17.0	+ 2.0	2	2	0
Low	1	121-202	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	0	38-120	3.6	2.9	- 0.7	27.1	33.0	+ 5.9	5	5	0
		Totals	13.3	8.8	- 4.5	100.0	100.0	0.0	17	17	0
		Net Manhour Change -33.8%									

	Mean Skill Level	Standard Deviation
Technology (Level 2)	274.3	137.6
Technology (Level 3)	263.8	140.0
Change	- 10.5	

TABLE C-6: MAINTENANCE LABOR FORCE SKILL DISTRIBUTIONS FOR NON-COMPUTERIZED (TL2) AND COMPUTERIZED (TL3) POWER PLANTS IN UTILITY J.

(b) Basis: Plant Operating Hour

Organization: Electric Utility J

Process: Power Production by Steam-Electric Process

Technology (Level 2): Centralized Control

Technology (Level 3): Centralized/Computerized Control

Source of Data: Direct Observation and Firm's Records

Period: 1962-1966 (TL2) and 1964-1967 (TL3)

1		2	3	4	5	6	7	8	9	10	11
Skill Level		Skill Point Range	Manhours Per Plant Operating Hour			Manhours as % of Total for Technology Level			Number of Job Types		
			TL2	TL3	Change	TL2	TL3	Change	TL2	TL3	Change
High	6										
	5	449-530	0.1	0.8	+ 0.7	2.1	14.0	+11.9	1	2	+ 1
	4	367-448	0.7	0.2	- 0.5	14.9	3.5	-11.4	3	2	- 1
Medium	3	285-366	1.9	1.8	- 0.1	40.4	31.6	- 8.8	6	6	0
	2	203-284	0.7	1.0	+ 0.3	14.9	17.6	+ 2.7	2	2	0
Low	1	121-202	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
	0	38-120	1.3	1.9	+ 0.6	27.7	33.3	+ 5.6	5	5	0
		Totals	4.7	5.7	+ 1.0	100.0	100.0	0.0	17	17	0
		Manhour Change Due to Technology Change +21.3%									

	Mean Skill Level	Standard Deviation
Technology (Level 2)	274.3	137.6
Technology (Level 3)	263.8	140.0
Change	- 10.5	

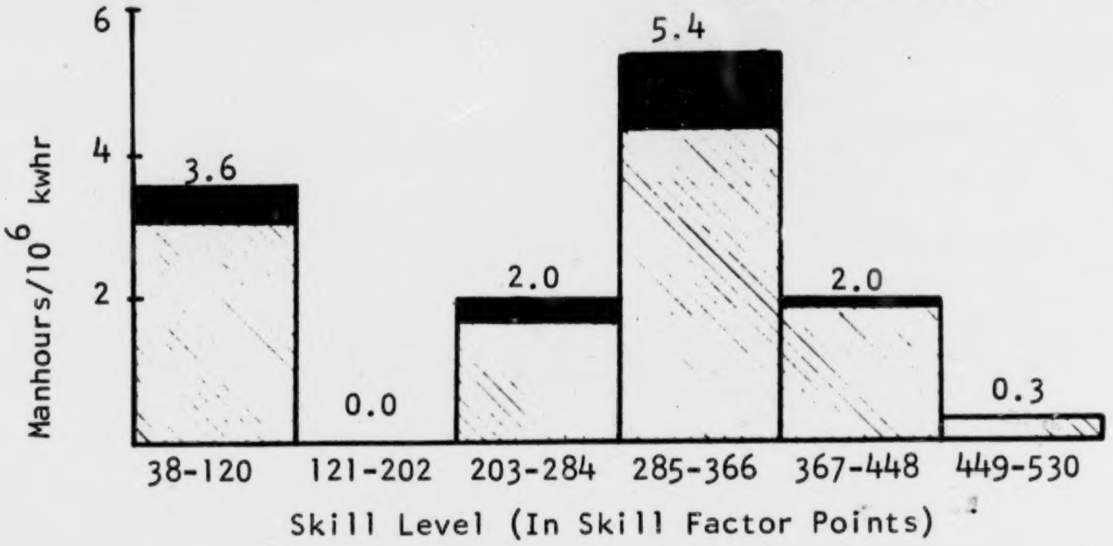
FIG. C-14: MAINTENANCE LABOR FORCE SKILL PROFILES FOR NON-COMPUTERIZED (TL2) AND COMPUTERIZED (TL3) POWER PLANTS IN UTILITY J.

(a) Basis: 10^6 Kwhr

▨ In-Plant Maintenace ■ Division Maintenace

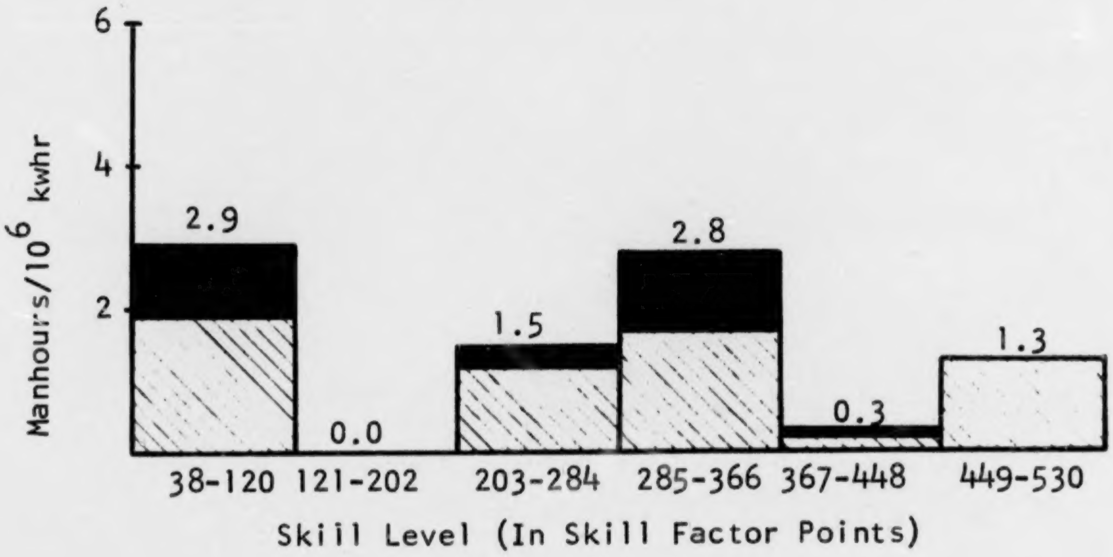
CENTRALIZED CONTROL

Total Manhours/10^6 kwhr = 13.3
Mean Skill Level = 274.3

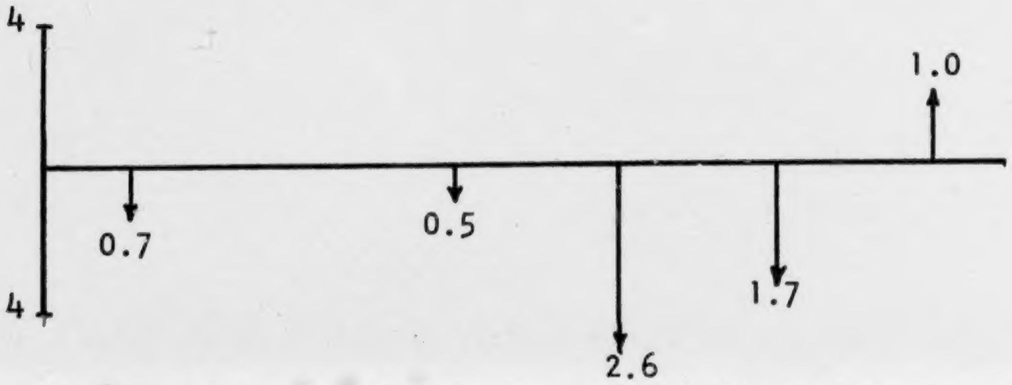


CENTRALIZED/COMPUTERIZED CONTROL

Total Manhours/10^6 kwhr = 8.8
Mean Skill Level = 263.8



CHANGES - OLD TO NEW TECHNOLOGY

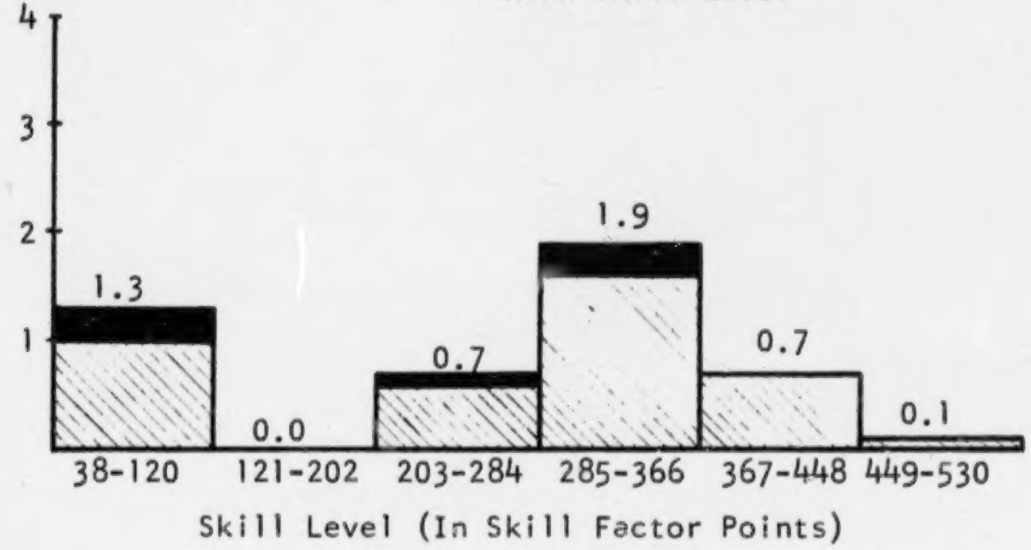


(b) Basis: Plant Operating Hour

▨ In-Plant Maintenance ■ Division Maintenace

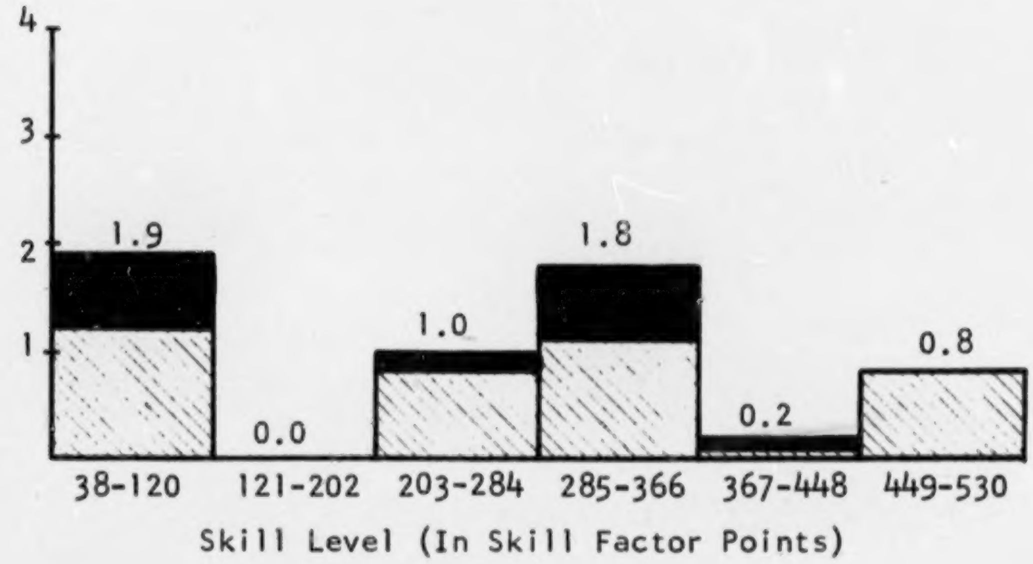
CENTRALIZED CONTROL

Total Manhours/Plant Operation Hour = 4.7
Mean Skill Level = 274.3

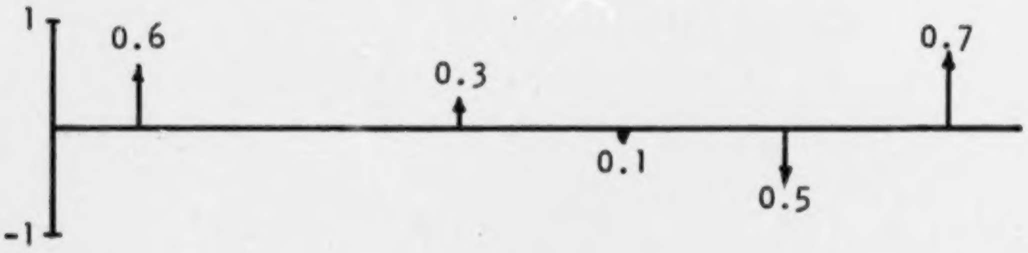


CENTRALIZED/COMPUTERIZED CONTROL

Total Manhours/Plant Operation Hour = 5.7
Mean Skill Level = 263.8



CHANGES - OLD TO NEW TECHNOLOGY



APPENDIX D

FLUID AND THERMOFOR HYDROCARBON CATALYTIC CRACKING IN OIL REFINERIES

1. OUTLINE OF PROCESS AND CONTROL TECHNOLOGIES

As the case study centers on the manpower and skill changes associated with changes in the control technology in catalytic cracking installations, detailed descriptions of either the Fluid or Thermofor processes will not be given here; these will be found in the relevant reference texts included in the bibliography of this report. The brief treatment presented below is given to facilitate understanding of the subsequent descriptions of the control technologies. It is perhaps worth mentioning here that Fluid and Thermofor catalytic cracking account for 70% and 23% respectively of the total catalytic cracking capacity in the U.S., with a third catalytic process--Houdriflow cracking--accounting for the remainder. This excludes the newer Hydrocracking process capacity.

Process Technologies

a. Fluid Catalytic Cracking (Figure D-1)

This process, commonly referred to as the F.C.C. process, derives its name from the fact that, when mixed with hot air or hydrocarbon vapor, the catalyst behaves like a liquid, circulating in a continuous flow between the reactor, a vessel where "cracking" takes place, and the regenerator, where contaminated catalyst is purified.

The reactor is fed with gas oil, some of which comes directly from the crude stills; the rest of the feed consisting initially of still heavier fractions, goes from the stills to a residuum stripper where the asphalt content is separated from the gas oil which is then passed through a furnace and into the reactor. As the catalyst from the regenerator flows in at the bottom of the reactor, it meets with the vapor-liquid mixture of gas oil. The heat of the catalyst causes further vaporization of the oil, as well as supplying the energy for the main reaction--"cracking." In the course of it, the larger molecules of the oil vapor are split into smaller molecules, and the resulting lighter vapors rise to the top of the reactor where they pass through cyclone separators; here the cracked oil vapors are separated from the heavier pulverized catalyst which drops to the bottom of the reactor to be returned to the regenerator.

After separation, the cracked oil vapors are piped from the top of the reactor to a fractionator. The fractionator effects a separation of the vapors, with gasoline and gas drawn off at the top and other products such as heating oil, cycle oil, etc., lower down the column. All these "cuts" subsequently undergo further refining and processing elsewhere in the plant. Some of the heavier cuts from the lower section of the fractionator are "recycled," i.e., merged with fresh feed and returned to the reactor.

Purification of the catalyst in the regenerator is achieved by burning off the deposited carbon under closely controlled conditions. Before return to the regenerator, an air blast is introduced into the stream of contaminated catalyst; the carbon and air mixture is generally sufficient to sustain spontaneous combustion, provided the supply of air is kept controlled. On those occasions when the oxygen content of the mixture becomes excessive, torch oil is sprayed into the regenerator to restore the balance.

b. Thermofor Catalytic Cracking (Figure D-2)

The Thermofor Catalytic Cracking process (T.C.C.) was first used commercially in the early 1940's. T.C.C. units are of the moving bed type, in which the catalyst flows through the reactor and regenerating kiln as a compact moving bed. As is shown in Figure D-2, the reactor is placed above the kiln. The catalyst flows by gravity from the surge separator through the reactor and into the kiln. Regenerated catalyst is returned to the surge separator by means of an air lift to complete the cycle.

The input material into the unit is gas oil coming from the crude stills and the residuum stripper. The gas oil enters the top of the reactor as a vapor-liquid mixture after having passed through a furnace. In the reactor, the gas oil vapors contact the catalyst from the surge separator and "cracking" occurs. During cracking, the gas oil vapors undergo a molecular change in which large molecules are split or "cracked" into smaller molecules. The products of this reaction are separated from the catalyst while passing through the vapor collecting grids at the bottom of the reactor. The recovered catalyst flows into the kiln while the cracked oil vapors enter the synthetic crude tower (fractionator). In the synthetic crude tower, which is an ordinary crude oil distillation unit, the cracked oil vapors are divided into various "cuts" from light gas to heavy oils by the process of fractionation. These "cuts," which are taken off as they leave at the temperatures of different levels inside the crude tower, are then further processed in auxiliary plants to make finished salable products or raw materials for use in other plants elsewhere in the refinery. Some of the heavier "cut" is returned to the reactor as recycle.

The recovered catalyst from the reactor, which contains coke deposits from the cracking process, flows from the bottom of the reactor into the kiln, where the coke is removed from the catalyst by burning with air. In the plume burner, which is the top one of the three sections of the kiln, the adhering liquids are burned off; and in the cocurrent section the remainder of the coke is removed. The coke deposit is generally sufficient to support combustion, which is regulated by varying the flow rate and the temperature of the combustion air blown into the kiln, as well as the distribution of the air throughout the kiln. Before entering the lift pot the catalyst is cooled. Some of the regenerated catalyst in the lift pot is returned to the reactor via the surge separator by means of the air lift.

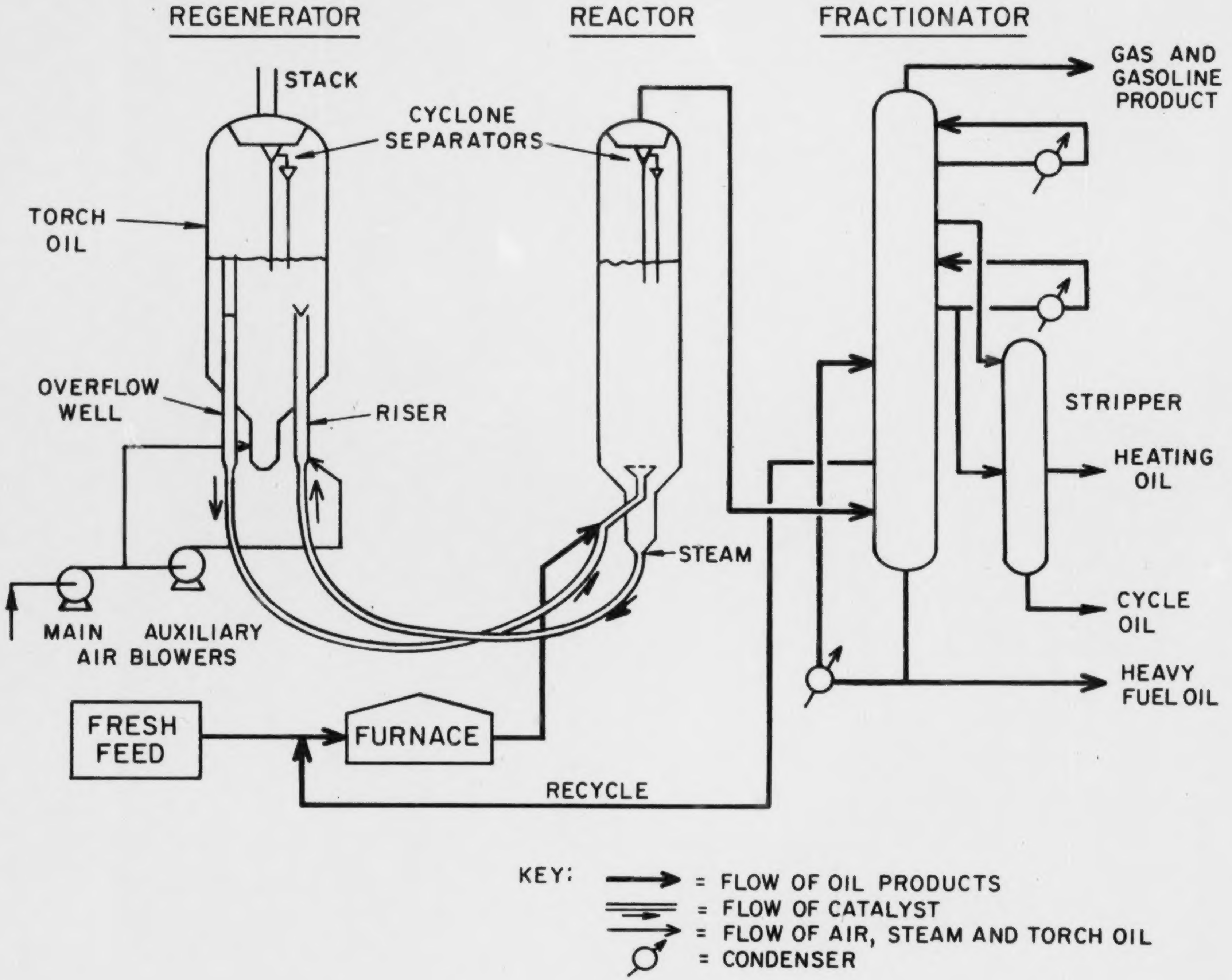

REGENERATOR
REACTOR
FRACTIONATOR
STACK
CYCLONE SEPARATORS
TORCH OIL
OVERFLOW WELL
RISER
STEAM
MAIN
AUXILIARY
AIR BLOWERS
FRESH FEED
FURNACE
RECYCLE
GAS AND GASOLINE PRODUCT
STRIPPER
HEATING OIL
CYCLE OIL
HEAVY FUEL OIL
KEY:
= FLOW OF OIL PRODUCTS
= FLOW OF CATALYST
= FLOW OF AIR, STEAM AND TORCH OIL
= CONDENSER

FIG. D-1: FLUID CATALYTIC CRACKING UNIT

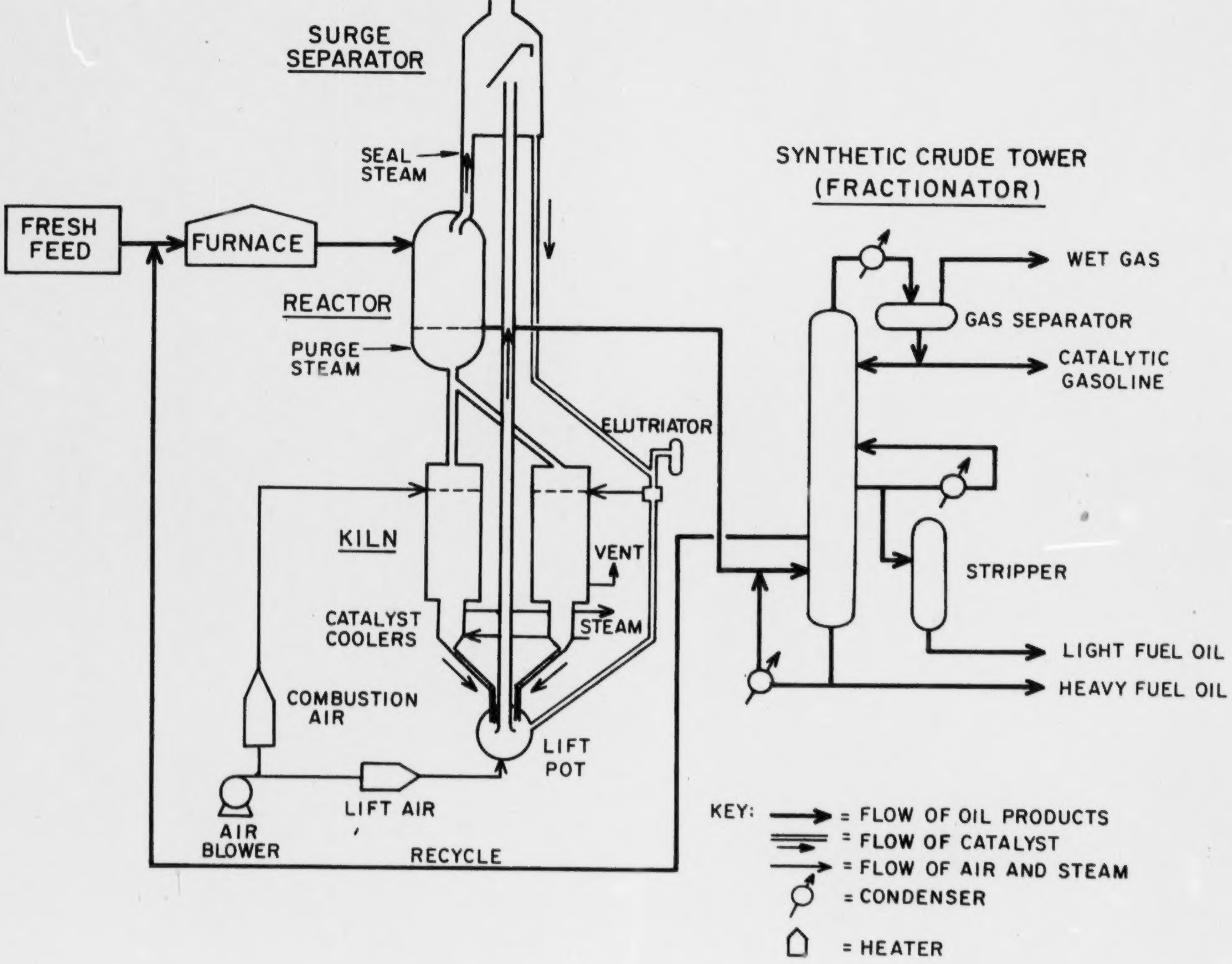

SURGE SEPARATOR
SEAL STEAM
SYNTHETIC CRUDE TOWER (FRACTIONATOR)
FRESH FEED
FURNACE
WET GAS
REACTOR
GAS SEPARATOR
PURGE STEAM
CATALYTIC GASOLINE
ELUTRIATOR
KILN
VENT
STRIPPER
CATALYST COOLERS
STEAM
LIGHT FUEL OIL
HEAVY FUEL OIL
COMBUSTION AIR
LIFT POT
LIFT AIR
AIR BLOWER
RECYCLE
KEY:
= FLOW OF OIL PRODUCTS
= FLOW OF CATALYST
= FLOW OF AIR AND STEAM
= CONDENSER
= HEATER

FIG. D-2: THERMOFOR CATALYTIC CRACKING UNIT

Control Technologies

Introduction of the computer for closed-loop control did not require any appreciable change in the control instruments in any of the three cracking units. A few instruments were added, mainly measuring and recording instruments and A/D and D/A converters; however, most of the control equipment and its layout remained unchanged.

Under the older technology, here referred to as pre-computerization, conventional (analog) automatic control devices were used to control various independent process variables, i.e., controlled variables. All of these control devices, consisting mainly of controllers and regulators, were air operated. The controllers and most of the recording and measuring instruments were located in the control room while the regulators were located out in the plant directly regulating the values of the appropriate plant variables.

A controller makes a comparison between the actual and the desired value of a variable and operates so as to reduce the difference between the two. It does so by transmitting a signal to the regulator, which in turn responds with a corrective action by opening or closing its passage for flow. The regulator is essentially an air operated valve, in which the rate of flow or the valve stem position is controlled by a variable pressure in the pneumatic capacity chamber that actuates the valve stem. Any change in this pressure is caused by signals from the controller in the form of a change in temperature, pressure, flow or any other variable with which the controller is associated.

Since most of the process dependent variables are determined by several controlled variables, the appropriate settings of the controllers are not obvious. Furthermore, in spite of the fact that standard minor loop controllers attempt to maintain constant values of the controlled variables, disturbances caused by variations in feed compostion, changes in performance of plant equipment, etc., may result in frequent readjustments of the set points of each controller in order to ensure favorable operating conditions. When making these readjustments, the operator usually changed one set point at a time. After each change he would check the values and trends of the variables concerned before making another change to the same set point or some other set point.

Limitations on production besides volume of fresh feed are mainly caused by the air blower supplying air for combustion in the regenerator and the compressor handling the gases from the reactor. The ideal operating condition normally requires the air blower and the compressor to be operated at maximum capacity. If however the compressor is operating at maximum while the capacity of the air blower is not fully utilized, then the operator would change the set-point of the heavy recycle stream controller to increase the amount of heavy recycle. Such an increase in bottom products from the fractionator joining the fresh feed into the reactor will result in increased production of lighter products such as gasoline, and also in an increased amount of coke deposit on the catalyst for supporting combustion in the regenerator.

By looking at the appropriate gauges or recording charts, the operator would be able to see the effect his changing of the recycle had on the production of gasoline and coke, as well as the operating conditions in the regenerator. After readjusting this set-point, the operator would change the set-point of the controller for the air blower in order to increase the air rate so as to provide more oxygen for burning the additional amount of coke deposit on the catalyst. After several such readjustments, the operator would obtain close to optimal settings for the controlled variables which in turn would put the dependent variables in their desired operating regions.

Under the newer technology, here referred to as post-computerization, the computer controls some of the process variables through its control program. These variables are some of the most critical ones in the sense that frequent readjustments of the set points for their associated controllers may be required and that the appropriate control of these variables largely determines product value and conversion.

As was the case under the older technology, the values of variables such as pressures, flow rates, etc., are available in the control room as low-pressure pneumatic signals. These signals are converted into electrical signals by means of transducers for entry to the computer terminal unit. Some variables e.g., temperatures and rpm's, are available directly as electrical signals. The measured values of these variables are recorded on devices such as electronic strip chart recorders. The values calculated by the optimizing computer control program are displayed on charts and printed out on a typewriter (A) as recommended settings for the controllable variables. The typewriter also prints out the values of the dependent variables as predictions based on the calculated values of the controllable variables.

Even though the computer automatically scans some one hundred variables and calculates the values of them, it actually controlls a small number of these variables. It does so by transmitting low-current electrical signals, corresponding to the calculated change in value of these variables, to the "set-point stations," one set-point station for each variable. The set-point station acts as a transducer and converts the electrical signals into pneumatic signals for the controller.

Computer Control Program

An integral part of this program is the set of equations relating the important plant variables. These equations are based on theoretical kinetic considerations and were developed from both computer simulations and commercial plant operations. The parameters in the equations are initially adjusted so that there is agreement between the measured value of a variable and the value obtained from the equations. These model equations, which are nonlinear, are then transformed into linear approximations and used in a linear program. This program optimizes product value, which is frequently the same as maximizing conversion, i.e., determine the value of plant controlled variables which will maximize product value within certain plant limits.

To prevent large changes from the operating points of the controllable variables during each optimizing step, move limits are placed on the magnitudes of these changes. Move penalties are assigned to each controllable variable so as to discourage changes in those variables which do not result in relatively large gains in product value.

The above description is based on the assumption of a steady state procedure. However, the catalytic cracking process is far from a steady state process. The plant-dependent variables may often change from their instantaneous values recorded at a given time without any changes being made in the controllable variables. Furthermore, because of time lags inherent in the process, change in a controllable variable is not immediately reflected in the dependent variables. The effects of non-steady state and time lags are provided for in the control program.

Certain special strategies are also used in addition to the basic optimizing control procedure. These strategies insure that corrective action will be taken whenever some plant variables are forced to operate in undesirable regions due to, for example, malfunction of some equipment.

Scan, Alarm and Logging Programs

In addition to the main control program, several other programs are incorporated into the computer software. One of these, the scan program, makes the computer scan some hundred plant variables at scanning frequencies of up to twenty variables per second. Each of these variables is read into the computer and updates previously stored values.

During scanning, the computer will detect any indications of instrument failure and, through the alarm program, notify the operator of such failure. Similarly, the operator will be made aware of instances when the value of some plant variable falls outside some preset limit for that variable. An alarm message is typed in red identifying the equipment and/or the variable concerned. The operator also receives the alarm message through an alarm annunciator, thus reducing delay and time spent on monitoring the various variables and equipment.

The logging program, which is very basic to the digital computer control of any process, provides an extensive log of the important plant variables to be printed out on a wide-carriage typewriter (B). The frequency of printout is determined by the operator so as to provide information in a convenient form logged for an eight-hour shift. A log may also be obtained by the operator on demand at any time.

Input/Output and Peripheral Equipment

Most of this equipment (see Fig. D-3) has been mentioned in the preceding pages. In addition to typewriters (A) and (B) and recorder pen traces for displaying calculated and measured values of plant variables, a paper tape punch is also available for use by the operator. This tape, however, is used mainly for recording data during plant shutdown or startup and while making certain plant tests. The tape is then used for offline analysis on another computer.

An essential component of the computer-operator interface is the operator's console through which the operator communicates with the computer. By means of switches and a decimal keyboard, the operator is able to obtain information from, and feed information into, the computer. The operator can, for example, change the values of plant equipment limits, instruct the computer how to operate in cases when some instruments are temporarily out of service, and request information regarding plant variables to be printed out on typewriter (B). After the operator has made an entry into the console, the computer program validates the entry and prints out whether or not the entry has been accepted. If an entry is not accepted, an error message is typed out explaining why the entry was rejected.

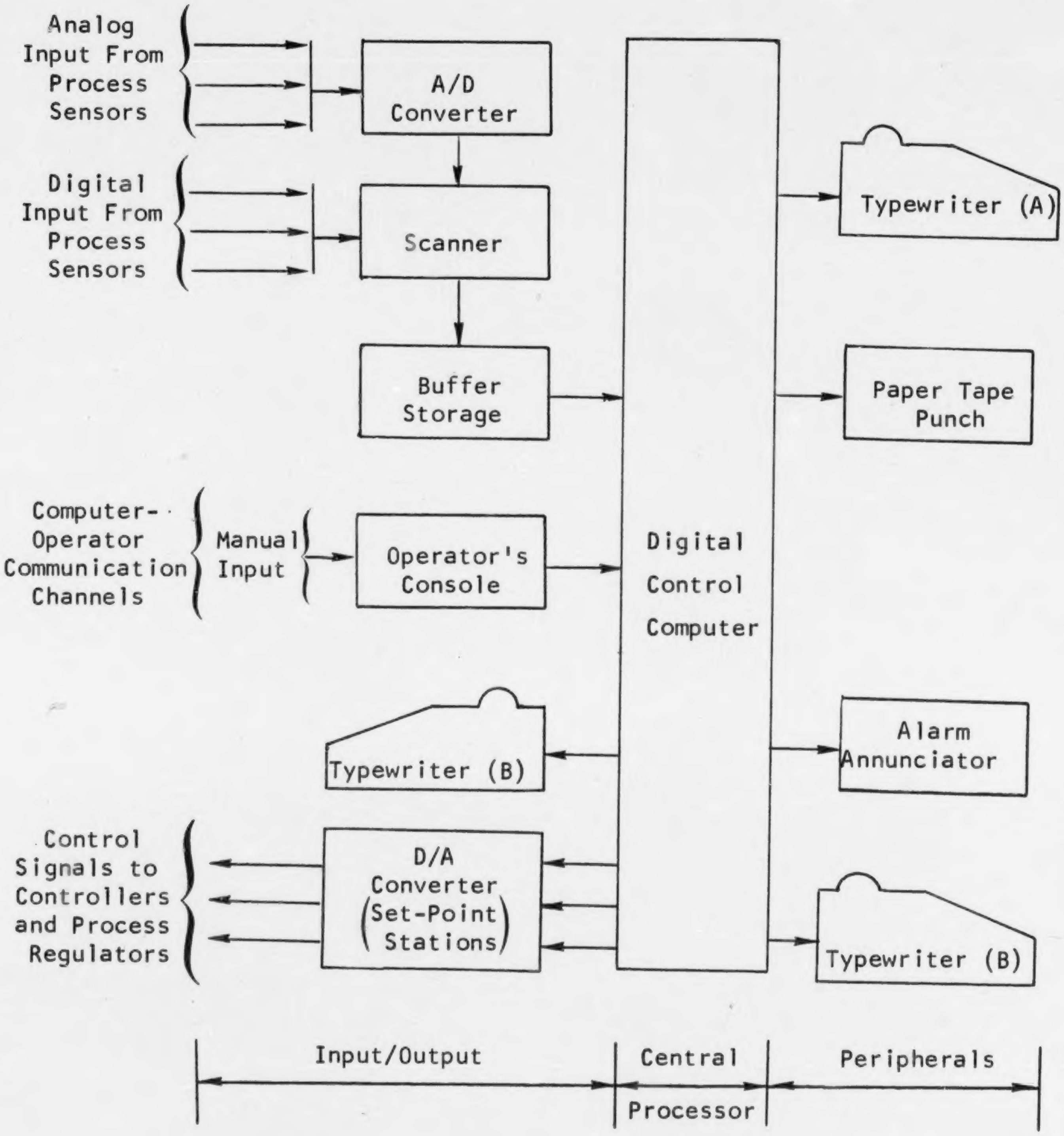

Analog Input From Process Sensors
A/D Converter
Digital Input From Process Sensors
Scanner
Buffer Storage
Computer-Operator Communication Channels
Manual Input
Operator's Console
Digital Control Computer
Typewriter (A)
Paper Tape Punch
Alarm Annunciator
Typewriter (B)
Control Signals to Controllers and Process Regulators
D/A Converter (Set-Point Stations)
Typewriter (B)
Input/Output
Central Processor
Peripherals

FIG. D-3: SIMPLIFIED COMPUTER SYSTEM CONFIGURATION IN CATALYTIC CRACKING

2. METHOD OF DERIVING SKILL LEVEL VALUES

Skill-rating estimates for the jobs concerned were made by the researchers, a job rating plan developed by C.H. Miller[*] being used for this purpose. Two factors out of a total of six were considered to be indicative of the skilled aspect of operator performance.

Experience & Training	0 - 400 points
Mentality	0 - 100 points

Experience and training are considered together, the aggregate time required for both being the basis for the assignment of evaluation points. Past experience required before assignment on the job is considered together with learning and practice time required after starting on the job.

Mentality is defined as "the prerequisite mental capacity and prior knowledge acquired through formal schooling or its equivalent in experience, necessary for the normal development of skills and knowledges for the job." Five degrees were considered depending upon the complexity of the job and the mental development required for its successful performance.

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[*] C.H. Miller. "Wage and Salary Determination." Union Oil Company of California, Industrial Relations Department (undated).

3. RAW DATA USED FOR DERIVING SKILL PROFILES

These data are tabulated under the title of each process, with the volume of fresh feed per shift in parentheses. The following notes explain the meaning of each column in the tables:

Job Code: The codes are assigned to each job to facilitate cross-referencing. The letter identifies the firm, the attached figure identifies technology and the figure separated by a dash, the job.

Job D.O.T. Number: These six digit numbers are taken from the 1965 edition of the Dictionary of Occupational Titles. The matching of D.O.T. number and job was done by the researchers on the basis of job description and their own knowledge of the jobs.

Job Title: Official titles assigned to the jobs by the firm.

Skill Level: Total skill factor points derived as explained in the preceding section.

Manhours: Determined from crew requirements established by the firm.

Volumes: Obtained from personnel familiar with the operation of the unit.

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
G1 F.C.C. (Volume: 18,300 barrels fresh feed per shift)				
H1 F.C.C. (Volume: 16,000 barrels fresh feed per shift)				
G,H1-1	542.280	Head Operator	460	8
G,H1-2	546.782	Unit Operator	420	8
G,H1-3	546.782	Operator (s)	340	40
G,H1-4	546.782	Operator (s)	340	40
G,H1-5	546.782	Operator (s)	340	40
G,H1-6	546.782	Operator (s)	340	40
G,H1-7	546.782	Operator (s)	340	40
G2 F.C.C. (Volumn: 18,300 barrels fresh feed per shift)				
H2 F.C.C. (Volume: 16,000 barrels fresh feed per shift)				
G,H2-1	542.280 213.382	Head Operator	460	8
G,H2-2	546.782 213.382	Unit Operator	420	8
G,H2-3	546.782 213.382	Operator (s)	340	40
G,H2-4	546.782 213.382	Operator (s)	340	40
G,H2-5	546.782 213.382	Operator (s)	340	40
G,H2-6	546.782 213.382	Operator (s)	340	40
G,H2-7	546.782 213.382	Operator (s)	340	40

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Shift
I1 T.C.C. (Volume: 6000 barrels fresh feed per shift)				
I1-1	542.280	Operator 1	460	8
I1-2	546.782	Operator 2	440	8
I1-3	546.782	Operator 3	410	8
I2 T.C.C. (Volume: 6000 barrles fresh feed per shift)				
I2-1	542.280 213.382	Operator 1	460	8
I2-2	546.782 213.382	Operator 2	440	8
I2-3	546.782 213.382	Operator 3	410	8

4. LENGTH OF OPERATORS' ON-THE-JOB EXPERIENCE

The job codes and job titles used in the previous section are retained for cross-reference.

Estimates of on-the-job experience required of the operators were made by the researchers in cooperation with representatives of the firms.

REFINERIES G AND H

Job Code	Job Title	On-the-Job Experience (Years) 0	1	2	4	6	8	9	10
G, H1	F.C.C. (PRE-COMPUTERIZATION)								
G,H1-1	Head Operator							X	
G,H1-2	Unit Operator					X			
G,H1-3 : 1-7	Operator (s)			X					
G, H2	F.C.C. (POST-COMPUTERIZATION)								
G,H2-1	Head Operator							X	
G,H2-2	Unit Operator					X			
G,H2-3 : 2-7	Operator (s)			X					

REFINERY I

Job Code	Job Title	On-the-Job Experience (Years) 0	4	6	8	9	10
I1	T.C.C. (PRE-COMPUTERIZATION)						
I1-1	Operator 1					X	
I1-2	Operator 2				X		
I1-3	Operator 3			X			
I2	T.C.C. (POST-COMPUTERIZATION)						
I2-1	Operator 1					X	
I2-2	Operator 2				X		
I2-3	Operator 3			X			

5. ACTIVITY ANALYSIS

The data for the following tables are based on observations made on the operator crew in the F.C.C. unit of Firm G by three different observers over three shifts. These observations, which reflect the number of hours each operator spends on the various activities averaged over a 40 hour working week, are "corrected" observations i.e., time for unnecessary, excessive and unusual functions is eliminated while time for necessary functions either not performed or partially done is added to the actual observations.

The Tables include the following activities:

Verbal Communication:	Receive and give information regarding turnover of the operating situation; receive and give work direction; contact other members of the crew regarding unit operations.
Monitoring and Control:	Read and record measuring instruments; inspect and adjust control instruments.
Miscellaneous:	Includes the running of plant control tests, reviewing laboratory test results, performing minor maintenance including lubrication of equipment outside the control room, and housekeeping.

The second line from the top of both tables gives the job codes of each of the seven operators, which is consistent with the job codes used throughout this Appendix.

Activity	Operator Hours Worked							Crew Total	
	G1-1	G1-2	G1-3	G1-4	G1-5	G1-6	G1-7	Hrs.	%
Verbal Communication	5.0	2.0	1.5	1.0	3.5	1.0	1.0	15.0	5.5
Monitoring and Control	10.5	17.5	10.5	11.0	19.0	17.0	15.0	100.5	35.9
Miscellaneous	1.0	0.5	1.0	7.0	1.5	6.0	10.0	27.0	9.6
Hours/week active	16.5	20.0	13.0	19.0	24.0	24.0	26.0	142.5	51.0

TABLE D-1

ACTIVITY ANALYSIS BEFORE COMPUTERIZATION (REFINERY G)

Activity	Operator Hours Worked							Crew Total	
	G2-1	G2-2	G2-3	G2-4	G2-5	G2-6	G2-7	Hrs.	%
Verbal Communication	8.0	3.5	2.5	1.5	4.5	2.0	1.0	23.0	8.2
Monitoring and Control	9.5	15.0	14.5	14.5	11.5	15.5	14.0	96.5	33.8
Miscellaneous	3.5	3.5	6.0	8.0	1.5	6.0	10.0	38.5	13.8
Hours/week active	21.0	22.0	23.0	24.0	17.5	23.5	25.0	156.0	55.8

TABLE D-2

ACTIVITY ANALYSIS AFTER COMPUTERIZATION (REFINERY G)

APPENDIX E

AIR SEPARATION (CHEMICAL INDUSTRY)

1. TECHNOLOGY

a. Physical Process

The physical process is the same at both levels with certain minor exceptions. In the following brief process description, air will be regarded as a mixture consisting of 78 per cent nitrogen, 21 per cent oxygen and 1 per cent argon by volume. The presence of rare gases other than argon such as helium, neon, krypton and xenon will be ignored. The removal of carbon dioxide and moisture will be specifically mentioned.

The separation of air at low temperatures involves refrigeration and a distillation process. Refrigeration is achieved by first compressing the air and then expanding it in an expansion engine. Distillation is accomplished by means of the fractionating process. Figures E-1 and E-2 give a simplified process flow description and a diagram of the fractionation columns of the computer controlled dual plants.

Atmospheric air is drawn in through the inlet air filter and compressed in the reciprocating air compressor. Five compressors operating in parallel compress the air from ambient pressure to about 2800 psig.* Each compressor takes the air through five stages of compression and between each stage the compressed air goes through an intercooler for removal of the heat of compression. After the final stage of compression, the air goes through the aftercoolers, one for each compressor. Both the intercoolers and aftercoolers are air and water coolers.

As the air emerges from the aftercoolers at a pressure of about 2800 psig and at approximately ambient temperature 70°F, it is passed through two freon coolers in parallel that lower its temperature to 40-50° F. The air is then passed through a molecular sieve adsorber for the removal of carbon dioxide and moisture. The molecular sieve adsorber is essentially a selective desiccant, an inorganic substance with a specific pore size. The pore size, pressure and temperature are such that nitrogen, oxygen and argon molecules are allowed to pass through, while molecules of carbon dioxide and water are attracted to the molecules of the inorganic granules and condensed on their surface. At a given temperature and pressure, the amount of carbon dioxide and moisture that will be adsorbed depends mainly on the pore size and the total area of the pore surfaces.

The air, which has had the carbon dioxide and moisture removed, emerges from the molecular sieve adsorber at about the same pressure and temperature at which it entered. The air stream is now split into two branches, each passing through a heat exchanger where the air is cooled to about -20° F by the waste nitrogen stream from the main fractionation column. The high-pressure air is subsequently passed through two freon coolers where it is cooled to -50° F. Each branch is again split into two as it emerges from the coolers; one stream goes through an expansion engine and performs external work, the other is further cooled in a heat exchanger and throttled through an expansion valve. The two streams are then recombined at a pressure of about 80 psig and a temperature of -250° F and fed to the high-pressure column of the fractionation unit. There is one such unit for each of the two plants.

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*psig = pounds per square inch (gravitational unit)

During the fractionation process, which will be discussed in some detail at the end of this section, the oxygen, nitrogen and argon are separated from the vapor feed in the fractionation columns. Argon is further purified in a redistillation unit. The final liquid product streams of oxygen, nitrogen and argon are then piped into 50,000 gallon storage tanks.

The Air Compressors -- The air compressors are five stage, horizontal, balanced-opposed and water-cooled reciprocating machines with synchronous electric motor drives. Each stage has a compression ratio of roughly 3 to 1.

The Expansion Engines -- The expansion engines are vertical, two cylinder, reciprocating machines. Each of them is started and loaded by an electric motor which, when run above its synchronous speed, operates like a generator and feeds power into the electrical mains. The compressed air is expanded in the machine, which is essentially a piston-cylinder device similar to a steam engine, and performs external work. The energy recovered is used to generate power by operating the electric motor or generator. While performing this work, the air loses an equivalent amount of heat energy and becomes cooler. About 70 per cent of this cooling is the result of performing external work and the Joule-Thomson effect accounts for the remaining 30 per cent.

Carbon Dioxide and Moisture Removal -- In the computer controlled plants, carbon dioxide and moisture in the air feed are removed by means of a molecular sieve adsorber. Adsorption is believed to be based on molecular attraction (van der Waals forces) between the molecules of a solid and those of a gas. The substance used is very porous with carefully controlled pore size. The effective area of the pore surfaces is enormous, which makes them capable of adsorbing large quantities of carbon dioxide and moisture. The molecules of the first layers are attracted most strongly, the forces of attraction diminishing with each subsequent layer. As the molecular sieve adsorber has to be regenerated about once every four hours, two such adsorbers (or rather two sections of one adsorber assembly) are used so that one is operating while the other one is being regenerated.

In the manually controlled dual plants, carbon dioxide is removed by passing the air through towers in which it is scrubbed with a countercurrent of caustic soda solution. Moisture and condensate are removed by adsorption in an air drier assembly consisting of pressure vessels and a desiccant. The towers, which

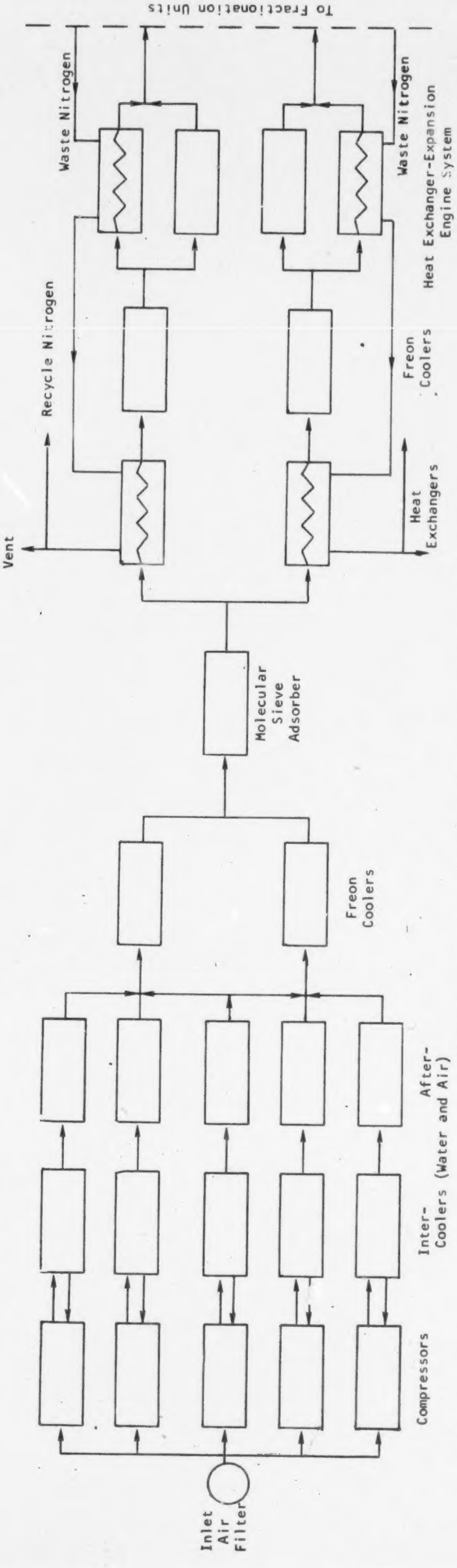
Inlet
Air
Filter
Compressors
Inter-
Coolers (Water and Air)
After-
Freon
Coolers
Molecular
Sieve
Adsorber
Vent
Heat
Exchangers
Recycle Nitrogen
Freon
Coolers
Waste Nitrogen
Heat Exchanger-Expansion
Engine System
Waste Nitrogen
To Fractionation Units

FIGURE E-1: PROCESS FLOW DIAGRAM OF THE TWIN AIR SEPARATION PLANTS

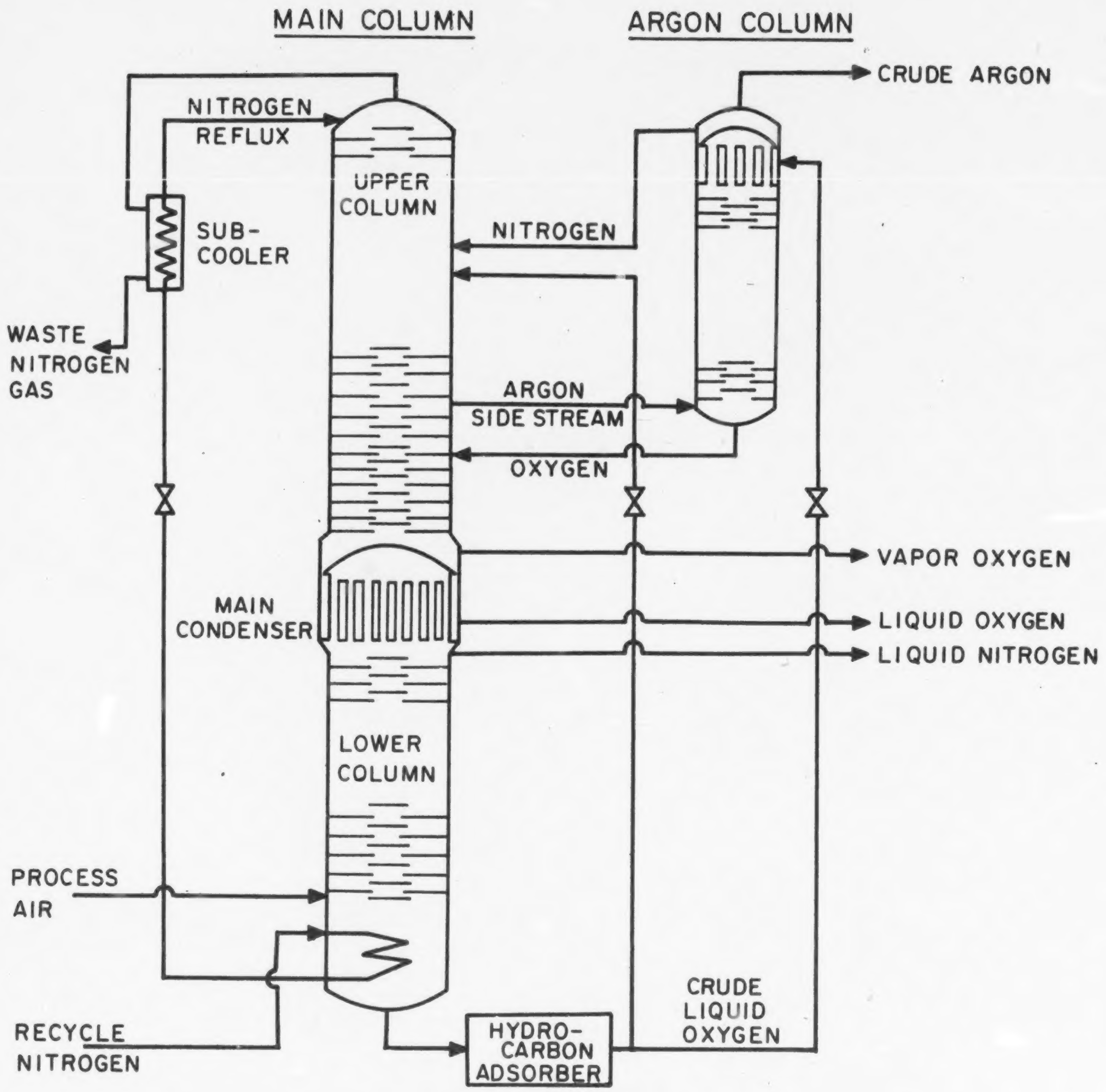
MAIN COLUMN
ARGON COLUMN
CRUDE ARGON
NITROGEN REFLUX
UPPER COLUMN
SUB-COOLER
NITROGEN
WASTE NITROGEN GAS
ARGON SIDE STREAM
OXYGEN
VAPOR OXYGEN
MAIN CONDENSER
LIQUID OXYGEN
LIQUID NITROGEN
LOWER COLUMN
PROCESS AIR
RECYCLE NITROGEN
HYDRO-CARBON ADSORBER
CRUDE LIQUID OXYGEN

FIGURE E-2: FRACTIONATION PROCESS WITH AUXILIARY COLUMN FOR SEPARATING ARGON are arranged in series, are filled with packing material over which the circulating caustic solution is sprayed. As the air flows upward through the tower, it contacts this caustic solution on the packing surface and the resulting chemical reaction converts carbon dioxide in the air to sodium carbonate. After about eight hours of continuous operation the spent caustic solution together with the sodium carbonate are drained off and replaced by a fresh supply of 9 per cent caustic solution.

Condensate produced in the compressor aftercoolers is removed in the purge bottles which are pressure vessels of the air drier assembly. The high-pressure air is then passed through one of two vertical pressure vessels for moisture removal. Each vessel is filled with an alumina desiccant and arranged for alternate operation to permit the reactivation of one while the other is in service. The vessels are switched about once every eight hours by manually operated valves.

Fractionation Process -- Fractionation of the air feed is accomplished in the main double-column and the argon column as shown in Fig. E-3. Without going into the design of these columns and the thermo-dynamic theory of the process in any detail, the following is intended to give an outline of the fractionation process in the Air Separation plants discussed here.

In air separation, as in any fractionation process, a liquid flows continuously down the column and interacts with vapor feed flowing upward through plates or trays. Throughout the column there is a continual change in composition of both the liquid and vapor phases. Proceeding from bottom to top of the column, the vapor phase increases in concentration of nitrogen, which is the more volatile component, while the liquid descending from plate to plate becomes enriched with the less volatile oxygen component. When the process is in the stage of dynamic equilibrium, liquid or vapor oxygen is continuously withdrawn from the bottom of the column and impure nitrogen vapor from the top.

The two-column arrangement of the main column is designed so that the reflux condenser of one column serves as the reboiler of the other and embodies as an essential feature a difference in pressure between the upper and lower column. This pressure differential across an evaporator-condenser interposed between the two columns (the main condenser) is so selected that the evaporation of liquid exygen in the condenser causes condensation of the nitrogen vapor at the top of the lower column. Since the normal boiling point of oxygen is higher than that of nitrogen, the pressure in the upper column has to be lower than that in the lower column.

In the lower column, the air is separated into a crude liquid oxygen bottom fraction and a gaseous nitrogen overhead stream. A portion of the nitrogen stream is totally condensed in the main condenser and piped from the column as the liquid nitrogen product stream. The remainder of this condensate, or reflux nitrogen, is passed through the reflux nitrogen subcooler in which it is subcooled by heat exchange against the waste nitrogen stream from the top of the upper column. The subcooled reflux nitrogen is subsequently expanded through a control valve and fed into the top of the upper column.

The crude liquid oxygen is withdrawn from the sump of the lower column, passed through hydrocarbon adsorbers, and then through the crude oxygen subcooler (omitted from diagram). The stream then splits in two, one being expanded through a control valve and fed to the upper column, the other passed into the condenser of the crude argon column before it is introduced as feed into the low-pressure section of the main column. This crude oxygen feed is then fractionated into a gaseous waste nitrogen overhead stream, a crude argon side stream and bottom product streams of vapor and liquid oxygen.

The waste nitrogen gas from the top of the upper column serves to subcool the reflux nitrogen and crude oxygen streams and to cool the high-pressure air passing through the heat exchangers as shown in Fig. E-2. Some of the waste nitrogen gas is then vented while a portion of it is used as recycle for the fractionation process.

The crude argon stream is piped from the main column at the level where the argon concentration is highest (10 per cent) and fed to the argon column for further fractionation. During this process, the argon is yet further separated from oxygen and nitrogen, which are returned to the appropriate levels of the main column. The crude argon overhead stream at a purity of about 96-98 per cent is then piped to the redistillation unit for further purification.

b. Control Systems

i) Technology Level 1 (Older Plants)

Along with introducing computer control of two new plants operating in parallel, operations were continued in the two older plants. One of them is entirely under manual control without the aid of any automatic control instruments. The operator controls the operation of this plant by adjusting all control valves. The newer of the old plants is equipped with conventional automatic control instruments, all of which are pneumatic. The controllers and most of the recording and measuring instruments are on a central control panel, while the control valves are located throughout the plant.

The controller, which is both a measuring and control instrument, makes a comparison between the actual and desired or set-point value of a process variable and operates so as to reduce the difference between the two. It does so by transmitting a pressure signal to the control valve, which in turn responds by opening / closing its flow passage. The rate of flow or the valve stem position is controlled by a variable pressure in the pneumatic capacity chamber that diaphragmatically actuates the valve stem; changes in this pressure are initiated by signals from its associated controller.

Since most of the dependent process variables are determined by several controlled variables, the appropriate settings of the controllers are not obvious. Furthermore, disturbances caused by variations in ambient pressure and temperature, changes in performance of plant equip-

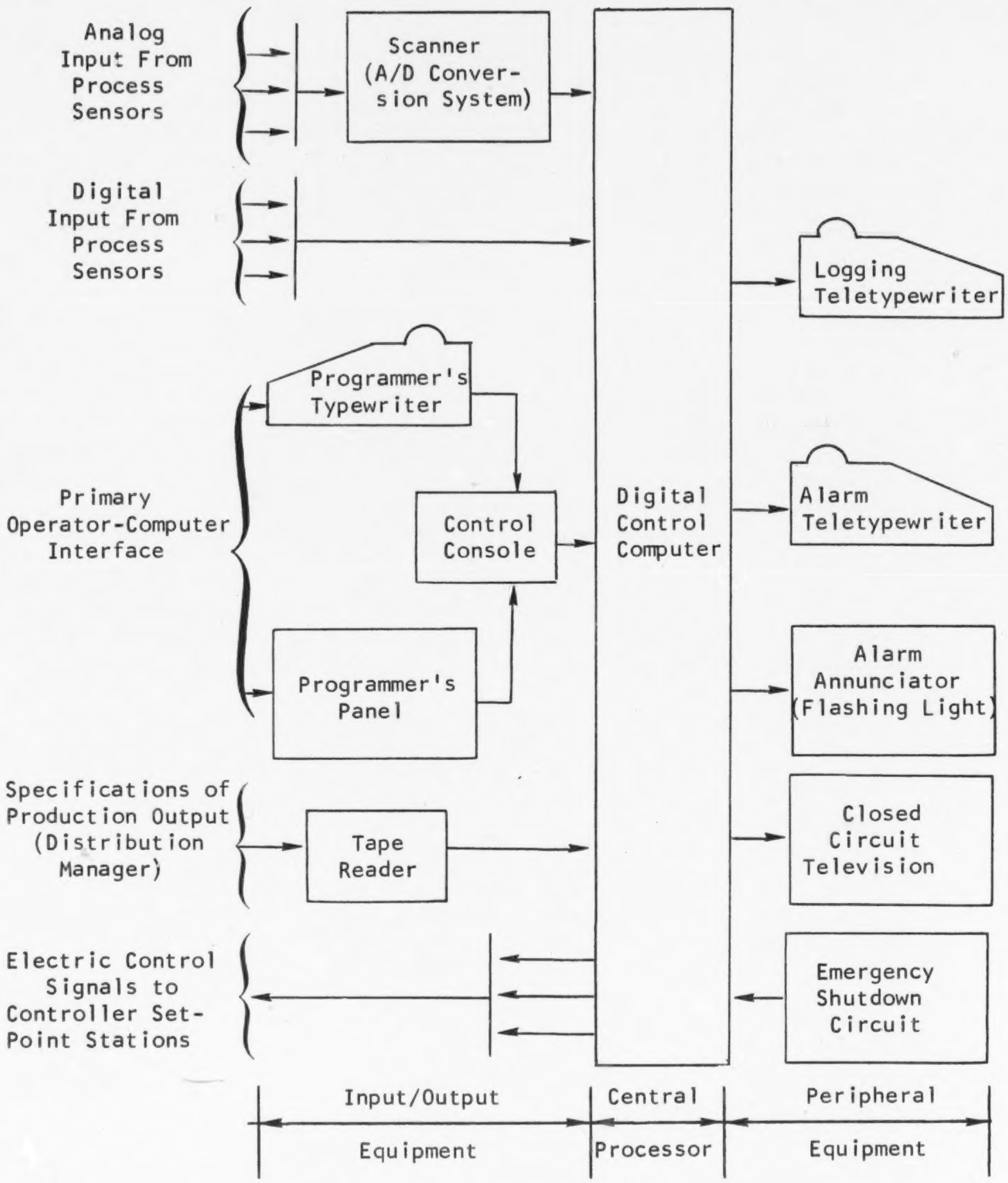
Analog Input From Process Sensors
Scanner (A/D Conversion System)
Digital Input From Process Sensors
Programmer's Typewriter
Primary Operator-Computer Interface
Control Console
Programmer's Panel
Specifications of Production Output (Distribution Manager)
Tape Reader
Electric Control Signals to Controller Set-Point Stations
Digital Control Computer
Logging Teletypewriter
Alarm Teletypewriter
Alarm Annunciator (Flashing Light)
Closed Circuit Television
Emergency Shutdown Circuit
Input/Output Equipment
Central Processor
Peripheral Equipment

FIG. E-3: SIMPLIFIED COMPUTER SYSTEM CONFIGURATION IN AIR SEPARATION ment, etc. may require frequent readjustments of the set points of some controllers in order to maintain favorable operating conditions. When making these readjustments, the operator will usually change one set point at a time. After each change he will check the values and trends of the variables concerned before making another change of the same or some other set point.

The activities of the single operator who maintains operations in the two old units, consists mainly in manipulating various controllers, monitoring recording and measuring instruments and turning control valves. He adjusts the various set points by moving a knob on each controller (or opens and closes control valves) so as to maintain the desired operating conditions. Even though the operator does not know the mathematical and thermodynamic relationships between the different process variables, he has been trained to recognize the most important interdependencies. Thus, for example, if a certain product stream is found to be below the requirement in terms of purity, he may decide to reduce the flow rate of this stream by changing the set point of the associated flow controller. He recognizes the relationship between stream composition and flow rate in terms of what effects his changing the flow rate will have on the composition of the stream.

Similarly, the operator has to maintain certain heat and refrigeration balances by controlling temperatures, pressures, etc. at various locations throughout the system. He does not recognize these balances as such but has been trained to do the right thing.

ii) Technology Level 2 (Newer Plants)

In contrast to the older technology outlined above, the two new plants are entirely operated by a digital process-control computer. Instead of an operator, it is the computer that changes the set points so that they correspond to the desired values of the process variables calculated by the control program.

The computer automatically scans several hundred variables, all of which are available in the control room as electrical current or voltage signals. Most of the signals are in the form of electrical currents which are transformed into voltages by passing certain current ranges through resistors. Some of the signals, which are initially pneumatic, are converted into voltages by means of transducers. Relatively few of the variables have their measured values indicated and recorded on instruments in the control room, as the corresponding information is provided by the computer's logging functions.

The various voltage signals, which are usually within the ranges of 1-5 or 1-10 volts, are read into the computer's analog-to-digital conversion unit and stored in the computer memory in the form of digits. Whenever the computer requires to know the value of some process variable in a control computation, for example, it picks the corresponding digit and converts it into an engineering unit by means of a conversion equation. A conversion equation simply describes the relationship between the digital equivalent of an instrument reading and the corresponding true engineering unit. Thus, a certain liquid level may be read as being somewhere within the range of 1 to 5 volts while the same range in terms of engineering units will be 0 to 100 inches. Instruments usually have their own individual conversion equations, some of which are linear while others are of a higher order. A square root relationship exists, for example, between the voltage readings and engineering units of flow rates.

The analog output system is exactly the reverse of the digital input system. After the computer has calculated the desired value of a process variable by means of its control program, the voltage equivalent of this value in engineering units is transmitted to a remote set-point station. This voltage value is generated from the corresponding engineering unit after the computer has solved the conversion equation (i.e., the reverse of the conversion equation of the incoming signal) and read the digital value into its digital-to-analog conversion unit. The signal then arrives at the set-point station which responds by changing a controller set point if the voltage value of the signal is different from the present set-point value.

A set-point station is essentially a servomechanism consisting of a small motor driven device and a balancing circuit. Upon receiving the voltage signal from the computer analog output system, the motor of the set-point station starts rotating until electric balance is restored. Since this motor is connected to a controller by means of gear wheels, any rotation of the motor physically moves the controller set point.

Once the set point is changed, the computer will take no further action until such time as another change of the set point is required. From here onward the control of the process variable is entirely independent of the computer and is similar to that for the older technology described above.

c. Computerized Process Control

i) Special Instrumentation for Computerization

Standard set-point stations are mainly available for control of pressure, liquid levels, flow and temperature. Some 15 such set-point stations are used with only minor modifications. Special control systems were designed for certain very low temperature control applications. Similarly, a servo-system was designed for the purpose of controlling the inlet valve timing device associated with the expansion engines of the refrigeration circuit. This timing device, which is under computer control, determines the air throughput of the expansion engines and hence the refrigeration efficiency. Hydraulic rather than pneumatic control is used for this purpose. The electric signal from the computer is transduced into a pneumatic signal, which in turn exerts pressure on a hydraulic reservoir. Changes in the hydraulic pressure move a cylinder which positions certain cams connected to the inlet valves of the expansion engines.

The computer is provided with information on important stream compositions by means of stream analyzers, which are operated on a time-sharing basis. Instead of using one analyzer for each stream, the computer is programmed to switch each instrument from one stream to another. Each of these analyzers transmits voltage signals within the range of 1 to 5 volts to the computer and records the same values on a rotating paper disc that makes one revolution every 24 hours. The disc has radial lines at 15 minute intervals and this makes it easier to relate the occurence of product impurities to some other plant upset.

Out of a total of six analyzers, three are used for measuring the compositions of the oxygen, nitrogen and argon streams from the two fractionation units. The oxygen and nitrogen analyzers are used strictly for protecting the liquid products in the storage tanks: whenever the purity of the oxygen goes below 99.5%, and oxygen contamination of the nitrogen exceeds six parts per million, the computer is programmed to dump production.

The remaining three analyzers plus the argon analyzer are used for control purposes only. The argon analyzer provides the computer with the feedback necessary for ensuring proper composition of the vapor argon stream which leaves the fractionation unit for further purification in the argon redistillation unit. Three analyzers are connected to intermediate streams that are merely indicative of certain aspects of the fractionation process.

ii) Computer Control Program

Integral to this program are the various relatively simple equations relating the dependent process variables to the independent or controlled variables. These relationships are based on theoretical steady-state considerations, and on analyses of the actual dynamic behavior of attended air separation plant.

Even though the computer scans several hundred process variables, it only performs some 25 relatively complex control computations. In some of these, the computer runs various heat balances for determining the allocation of air through the expansion engines and heat exchangers. The actual control of the air throughput of the expansion engines is governed by the valve timing device mentioned earlier. Any air that is not expanded in the engines is passed through the cold branch of the heat exchangers.

Another important section of this program controls the air capacity of the five process-air compressors. The computer regulates the supply of air to the dual plants as well as the air pressure of the molecular sieve adsorber. This is accomplished by varying the air intake into "clearance pockets", and venting air through an atmospheric vent valve. Each compressor has two clearance pockets so that, for the five compressors combined, the computer controls over ten per cent of the total air volume. The vent valve permits another ten per cent of the air pool to be regulated by the computer.

The clearance pockets are essentially dead volumes connected to the cylinders via a clearance valve in the passage between each cylinder and the pocket. For maximum capacity and efficiency, the piston should travel so close to the cylinder head that all the air is pushed into the next stage. By opening the clearance valve to a pocket, some air idles in this dead volume so that not all of it is pushed into the next stage. Thus, the capacity of the compressors is reduced and an artificial inefficiency is introduced. When, for example, the molecular sieve adsorber is being repressurized (every four hours), the computer immediately senses that the supply of air to the plants is being reduced. The computer has been programmed to cope with this apparent air loss by gradually closing the valves to the clearance valves.

The various tasks performed by the computer are ordered in a sequence, priorities being dictated by the executive routine of the program. Thus, the more important tasks such as control computations have to be completed before the computer is available for performing lower priority tasks such as trend logging a variable. As soon as the computer has completed one task, it starts searching for the next lower priority task. During this short search period, a red light on the control console lights up, and this may occur some thirty times per minute. Even if this light lights up only once during a minute, it shows that the lowest priority task has not been truncated. Having completed one search cycle, the computer again starts to perform the highest priority task. A "priority interrupt" organization ensures that a lower priority command such as a trend log is interrupted whenever necessary for the completion of a higher priority task.

The performance of each sub-task has been programmed in a similar manner with regard to priorities. When, for example, the control program needs the value of a process variable, the first step is to check for signs of failure in the measuring instrument for this variable. If no such failure and no limit violation are indicated, the program will use the value in memory. The program may use a value if process limits have been exceeded; however, if an instrument breakdown is indicated, the value will not be used in any control computations. The computer will then revert to the last "good" set point and use it until the instrument has been repaired.

iii) Auxiliary Programs

In addition to the main control program, the computer has several other programs incorporated into its software. The most extensive one of these, the scan program, makes the computer "scan" (i.e., record the values of) several hundred process variables, updating previously stored values once every eight seconds. Higher scanning frequency is possible with the existing hardware; however, an eight-second scan is considered adequate in view of the relatively slow instrument response-time.

The values of those process variables which are sensed as digital signals are gated directly into the memory storate. Analog inputs, however, are first selected by a multiplex switching and passed to an A/D conversion unit. The converted values are stored in designated sections of the computer memory; no external buffer storage exists.

During scanning, the computer will test for any indications of instrument failure and process-limit violations. If an instrument failure results in an unreasonable measurement for the associated variable, the computer will "flag" this variable. Simultaneously an alarm program will cause an error-message identifying the instrument to be typed out on the remote teletypewriter monitored by an operator in the nearby attended plants.

If no instrument failures are indicated, the computer will examine the corresponding variables for violations of tolerance or process limits. Most of these limits are fixed, but the reciprocating machines (compressors and expansion engines) have variable limits for their associated variables. The variable limits are calculated by the computer on the basis of very simple equations relating variables such as compression and expansion ratios, cooling water temperatures, etc. Such variable limits have the advantage of being more accurate under changing operating conditions.

Besides alarm limits, each variable is assigned upper and lower shutdown limits, which are wider than the corresponding alarm limits so as to permit corrective actions to be taken by maintenance and avoid computer shutdown.

A logging program provides an extensive log of the most important process variables. Every hour on the hour the current values of 66 process variables are listed on the logging teletypewriter, which is a special slow-speed typewriter with a 30 inch carriage. A log may also be obtained at any time on demand. Values of variables for which process limits have been violated, are logged in red thus emphasizing the messages on the alarm typewriter.

The logging teletypewriter also presents an economic summary every 24 hours. It provides an analysis of the plants' performance in terms of product yield, on-stream time for certain process components, power consumption and efficiency.

A trend-log program greatly aids maintenance and supervisory personnel in cases of process and equipment problems. This program permits a number of process variables to be trend-printed at any frequency, such as once every minute or multiples thereof.

In addition to the above program features, load and utility programs are used as well as a number of convenience programs. The load and the utility programs, which are mainly used for making program changes, may only be activated from a programmer's panel by trained supervisory personnel. The convenience programs, which are initiated from a control console, are used routinely by plant maintenance personnel when making equipment adjustments.

A number of programs are also stored in the permanent guarded computer memory for the purpose of verifying the computer's own performance. One such routine makes the computer solve a problem and compare the result obtained with the correct stored result. Any significant disagreement between the two results will cause the computer to initiate an alarm and shutdown. Another routine makes the computer check its own input analog amplifiers for any calibration shift. It does so by impressing a small voltage across an amplifier, reading the amplifier and comparing this reading with some maintained standard voltage level. The computer will register any disagreement between the two readings as an amplifier drift, and type out the magnitude of this drift and the amplifier identification on the alarm typewriter for maintenance action. At the same time, the computer will compensate for such a drift by adding or subtracting the percentage corresponding to this drift to each value derived from the amplifier.

iv) Input/Output and Peripheral Equipment

Some of this equipment (see Figure E-3) has been mentioned previously. In addition to the alarm teletypewriter, logging teletypewriter, programmer's panel and control console, a programmer's typewriter and tape reader constitute part of this equipment. The programmer's typewriter, which is normally disconnected from the computer, is used for making program changes and for diagnosing abnormalities of instruments. The typewriter has a paper tape punch and a reader associated with it, and when a member of the maintenance staff wishes to call for a trend log or print out some portion of memory, he sets certain numerical dials located on the console to specify memory locations, punches his instructions onto the paper tape, passes the tape through the reader and then presses actuator buttons on the console.

The programmer's panel, which is only used by computer-trained personnel, permits access to the guarded computer memory. Such access is required when making certain program changes and for activating load and utility programs.

The quantities of liquid nitrogen and liquid oxygen to be produced are determined by the Distribution Manager who externally feeds a command tape specifying these quantities through a remote tape reader. The computer reads this instruction, stores the command data thus provided, and adjusts plant operation accordingly.

The alarm and logging teletypewriters provide the main communication links between the new plant and the operator of the older plant. A closed circuit television system and an emergency shutdown circuit are also available for his use but these are rarely if ever employed.

It will be seen from the above description that virtually all direct operating tasks and contingencies handled by the operator in older plants are now managed by the computer. In effect it is a perfectly responsive system for meeting production demands specified by the Distribution Manager. Direct-labor input has been effectively eliminated.

2. METHOD OF DERIVING SKILL LEVEL VALUES

Skill ratings for all the jobs concerned were obtained by the researchers in cooperation with representatives of the firm. A job rating plan developed by C.H. Miller* was used for this purpose. Two factors out of a total of six were considered:

Experience and training	0 - 400 points
Mentality	0 - 100 points

Experience and Training are considered together, the aggregate time required for both being the basis for the assignment of evaluation points. Past experience and education required before assignment on the job is considered together with learning and practice time required after starting on the job.

Mentality is defined as "the prerequisite mental capacity and prior knowledge acquired through formal schooling or its equivalent in experience, necessary for the normal development of skills and knowledges for the job." Five degrees were considered depending upon the complexity of the job and the mental development required for its successful performance.

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*C.H. Miller. "Wage and Salary Determination." Union Oil Company of California, Industrial Relations Department (Undated).

3. RAW DATA USED FOR DERIVING SKILL PROFILES

These data are tabulated under the title of the process and type of labor with the volume of the product processed per shift in parentheses. The following notes explain the meaning of each column in the tables:

Job Code:	The codes are internal codes, assigned to each job to facilitate cross referencing. The letter identifies the firm, the attached figure identifies technology and the figure separated by a dash, the job.
Job D.O.T. Number:	These six digit numbers are taken from the 1965 edition of the Dictionary of Occupational Titles. The matching of D.O.T. Number and job was done by the researchers on the basis of job description and their own knowledge of the jobs.
Job Title:	Official titles assigned to the jobs by the firm.
Skill Level:	Total skill factor points derived as explained in the preceding section.
Manhours:	Determined from crew requirements established by the firm and from discussions with personnel familiar with the operations.
Volumes:	Obtained from personnel familiar with the operation of the units.

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
N1 MANUAL CONTROL (Volume: 21.7 tons per shift)				
Direct Labor				
N1-1	559.782	Operator	160	8.0
Indirect Labor				
N1-2	559.132	Foreman	430	0.5
N1-3	630.281	Maintenance Mechanic	280	1.0
N1-4	630.281	Maintenance Helper	210	0.5
N1-5	710.281	Laboratory Technician	450	0.1
N1-6	710.281	Instrument Technician	500	0.0*
N2 COMPUTER CONTROL (Volume: 26.7 tons per shift)				
Direct Labor				
N2-1	559.782	Operator	160	0.0005
Indirect Labor				
N2-3	630.281	Maintenance Mechanic	280	1.0
N2-4	630.281	Maintenance Helper	210	0.5
N2-5	710.281	Laboratory Technician	450	0.1
N2-6	710.281	Instrument Technician	500	0.02

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*Time spent on maintenance of pneumatic control instruments is negligible.

4. LENGTH OF GENERAL EDUCATION AND ON-THE-JOB EXPERIENCE

The job codes and job titles used in Section 3 are retained for cross reference.

Estimates of general educational and on-the-job experience requirements were supplied by the firm.

Job Code	Job Title	Estimated Required Years of High School	College 0	College 2	College 4	On-the-Job Experience (Years) 0	2	4	6	8
N1	MANUAL CONTROL									
	Direct Labor									
N1-1	Operator	None				X				
	Indirect Labor									
N1-2	Foreman	None						X		
N1-3	Maintenance Mechanic	None					X			
N1-4	Maintenance Helper	None				X to	X			
N1-5	Laboratory Technician				X		X			
N1-6	Instrument Technician				X			X		
N2	COMPUTER CONTROL									
	Direct Labor									
N2-1	Operator*	None				X				
	Indirect Labor									
N2-3	Maintenance Mechanic	None					X			
N2-4	Maintenance Helper	None				X to	X			
N2-5	Laboratory Technician				X		X			
N2-6	Instrument Technician				X			X		

*Time spent by Operator (N1-1) on remote monitoring is essentially zero.

APPENDIX F

AIRLINE PASSENGER RESERVATION SYSTEMS

1. OUTLINE OF RESERVATION SYSTEMS TECHNOLOGIES

The essential services rendered by airline reservation systems are providing space and facilitating boarding onto the plane. The main points at which the activities involved in servicing passengers occur are the Reservation Offices and Ticket Offices which secure and hold space, the Airport Offices which assists passenger departure and arrival, and the central facilities which are the link between local offices.

Reservation Offices

A large and important segment of Reservation Office personnel are Reservation Agents who answer telephone calls from customers seeking to make reservations or desiring a variety of flight information. Calls are received from many different sources, all of which can loosely be called "customers". The most frequent types of customers are individuals, travel agencies, and commercial establishments. Other calls arrive from tour operators, the airline's own ticket offices which do not have access to centrally stored information, and offices of other airlines. Interline calls (calls between offices of different airlines) concern passengers transferring at some stage to connecting flights, whose reservations are taken by one airline but who are partly serviced by other airlines.

Owing to the diversity of call sources and the extensiveness of customer service provided by the airlines, the Reservation Office personnel must be capable of processing many kinds of information relating to reservations. These include:

1. Flight schedules of all airlines
2. Availability of seats on all flights of their own airline
3. Availability of seats on flights of connecting airlines
4. Passenger information
5. Special meal arrangements
6. Up-to-the-minute flight arrival times
7. Car rentals
8. Hotel reservations and facilities
9. Special requests for such services as bassinet, wheel chairs, etc.
10. Ticketing arrangements
11. Fare quotations
12. Currency and customs regulations (particularly for international carriers)
13. Tour arrangements

The basic document in the reservation procedure is the Passenger Reservation Record (PRR) which contains passenger information (name, address, phone), special provisions (e.g., passengers desiring seats together, requests for infant facilities, wheel chair, and special meals), hotel, tour, and car reservations requested, ticketing information (date and location where ticket is to be picked up), fare information, and international documentary requirements. The PRR serves as the source for adjusting seat availability inventory, providing special services and facilities, and providing subsequent forms for boarding passengers and taking post-departure action. Technological changes have not affected the status of the PRR which remains now, as it was before, the basic document. However, they did affect a) the method by which Reservation Agents acquire flight availability information which has to be communicated to prospective passengers before a booking can be made; b) the storage of PRRs and thereby the method of retrieval for amendment and other purposes.

In manual reservation systems, exemplified by N1 , the Reservation Office was typically divided into three sections: (1) The Sales Section which received incoming calls, provided flight information, and entered the PRR onto a reservations sales card at the time of booking (the Sales Section in Firm N's manual system was further divided into a subsection which received calls from the general public, other airlines, and ticket offices, and another which handled calls from travel agencies and commercial customers); (2) the Control Section which controlled all flights departing from the local airport, maintained a file of Passenger Reservation Records for local flights and used them to supply information as needed to passengers and company personnel. PRR's for flights leaving from another location were teletyped to the Reservation Office controlling those flights. The control section also computed fares for complex itineraries, made additions and changes to PRR's and supervised the issuing of tickets, ordering of meals and aircraft seating arrangements. (3) The third section, Communications, was staffed by teletype operators who transmitted messages reporting sales to Central Control and special requests, passenger reservation information, etc. to the local airport office as well as to other Reservation Offices.

Semi-automatic reservation systems such as P1 , were in many of their procedures similar to manual systems. The same information was recorded on the reservation sales card to create the Passenger Reservation Record but the content of all PRR's was teletyped to a central control facility which maintained the main PRR file. The central control facility also took over all functions of local control sections, which it replaced. Centralization of control functions radically reduced the number of teletype operators needed. To give Agents in individual offices access to seat availability status, Agent Sets resembling simple adding machines were introduced; these sets (see Fig. F-1) were electronically connected to a master control board at the central facility. Each set was equipped with so-called Destination Plates, enabling the Agent to request and receive simultaneously information on all direct, alternate, or connecting services to a particular destination. The plate was partitioned into sections of eight flights or flight legs (a leg is that part of a flight from one takeoff to the next scheduled landing). Asked about flights to

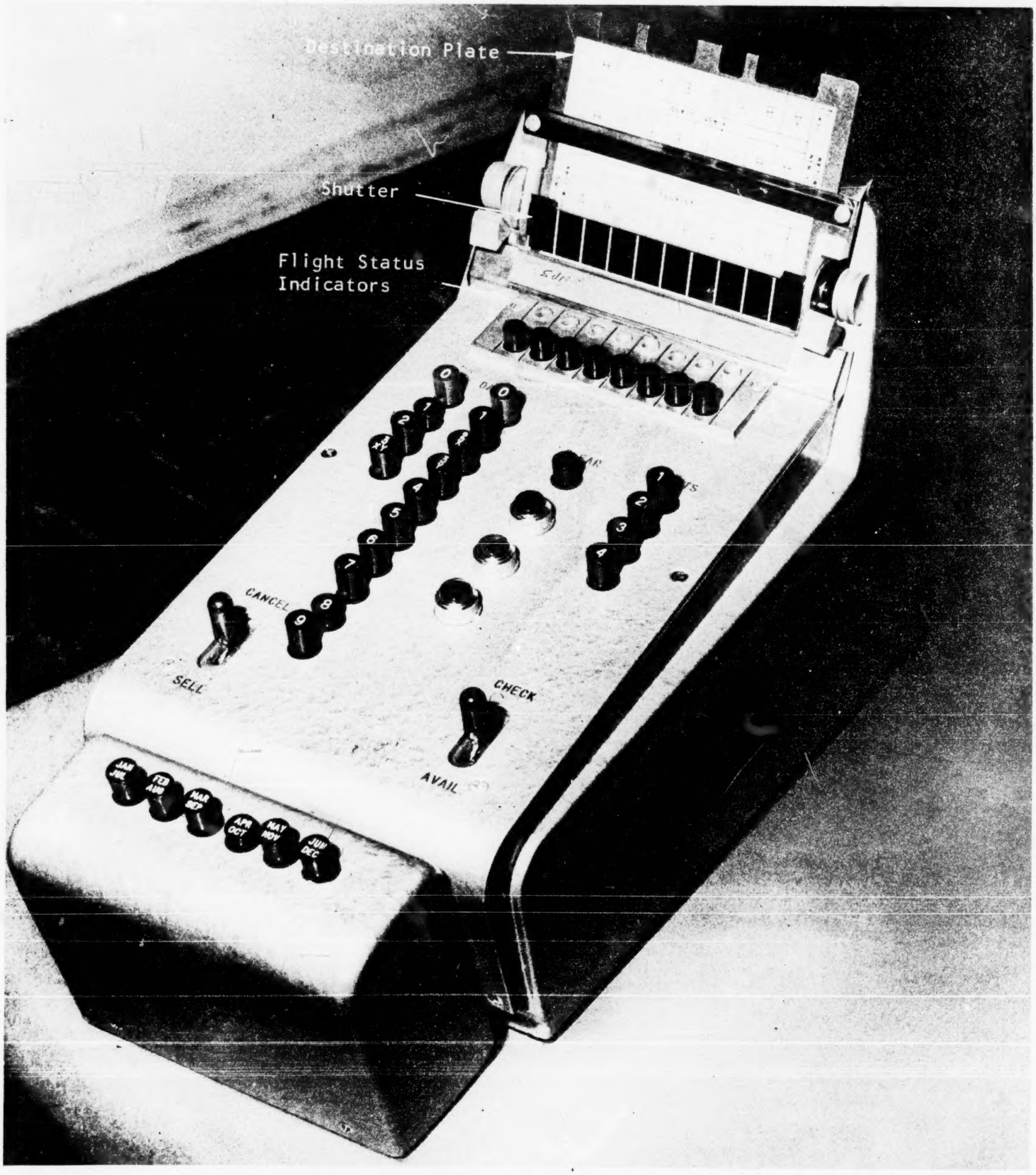
Destination Plate
Shutter
Flight Status
Indicators
CANCEL
SELL
CHECK
AVAIL
JAN JUL
FEB AUG
MAR SEP
APR OCT
MAY NOV
JUN DEC

ILLUSTRATION F-1: AGENT SET USED IN SEMI-AUTOMATIC RESERVATION SYSTEM (P1) a particular destination, the Reservation Agent inserted the appropriate Destination Plate in a guide on the back of the Agent Set and adjusted a shutter over the plate to designate for which group of eight flights the information was desired. The month and date of the desired flight were keyed in and the transaction was activated by positioning a lever on the set. Within seconds the availability status of all eight flights (or legs) was indicated by a small light indicator below each: a light on meant the flight was "open" and a seat reservation could be immediately confirmed to the caller, a light off signified flight was closed for further bookings, a flashing light indicated that the "stock" of seats was running out and space had to be requested by teletype, the caller to be informed of availability only after a reply was received. Other lights on the set indicated conditions such as a line failure or faulty operating procedure.

Reservations Offices under the computerized technology have Agent Sets which are directly linked to a central computer installation. The sets are much more sophisticated than those used in the semi-automatic system and, in conjunction with the computer, provide a much faster means of processing the necessary data in the system. The Agent Set shown in Figure F-2 comprises three components: The Air Information Device (AID), the Routine Action Pushbutton (RAP), and the Input/Output Keyboard and Typewriter (I/O). The AID is used in conjunction with a flight card (similar to the destination plate used in the semi-automatic system) which contains groups of flights to particular destinations. At the bottom of the flight card is a configuration of prepunched holes. Information on seat availability is obtained by inserting the card into the AID, which senses the holes, and keying in the desired date on the RAP. In reply, the status of each flight on the card is indicated by a row of lights located next to the flight card. To sell or reserve seats, the required information is input by depressing the AID flight button corresponding to the desired flight, entering the complete Passenger Reservation Record on the I/O typewriter and pushing the buttons for the desired date and the number of seats on the RAP; the transaction is completed by striking the "sell" button on the RAP (which also has buttons for initiating "cancel" and "ignore" transactions). The I/O is also used to obtain flight information and to receive and/or alter existing PRR's.

Cutting across and largely independent of technological changes are divergencies between airlines in their way of organizing the reception of incoming calls at Reservation Offices. In Airline N, one group of Agents handles interline, ticket office and "direct" (general public) calls, and another travel agent and commercial account calls. Airline P maintains a separate group for handling commercial accounts only, all other calls going to the second group of agents. In both airlines there are separate telephone lines for each category of customers and distribution to the appropriate group of agents is by an automatic switching device. At those times when all agents are busy, all new calls are queued up and distributed in order of arrival as agents become available.

The length of time each call has to wait in the queue is automatically recorded and the accumulated records provide a form of control on office performance and are used to determine manning requirements; companies aim to keep the number of Sales Agents large enough for about 90% of the incoming calls to be answered in less than 20 seconds from their arrival in the queue. Also recorded is the time required to service a call, which depends on its source and the nature of the information involved. On average, calls take about 3 minutes to process. Many callers inquire about flight schedules, fares, and other information, but calls do not result in bookings; in general, the ratio of calls to number of passenger boarded varies between 2 and 4 in one firm and 5 to 6 in the other.

City Ticket Offices

In contrast to the Reservation Office where all contacts with the public are via telephone, City Ticket Office (CTO) functions involve face-to-face contact. Activities include making reservations, issuing tickets, and planning itineraries. These same services are also provided by the Reservation Office and Airport Ticket Office, but the City Ticket Office is a convenience for the customer. CTO's are usually maintained in large hotels, shopping centers, and other areas which are accessible to a large number of people.

The functioning of ticket offices have been affected very little by the changes in reservation technologies. Except in extremely busy offices there are no Agent Sets. Instead, reservation and ticketing information is relayed through the Reservation Office. When a ticket is picked up, the Ticket Office salesman notifies the Reservation Office so that the Passenger Reservation Record can be brought up to date. With the increased use of ticketing by mail, City Ticket Offices service a smaller percentage of passengers.

Airport Office

The basic process of boarding passengers onto the aircraft involves several standard activities which include processing reservations, checking baggage, assigning seats, processing information required for providing special services, and compiling flight reports. The differences in procedures used to effect these functions derive from the type of passenger serviced as well as the state of the technology. The information in Table F-1 summarizes these differences.

The processing of reservations under each technology is accomplished in the same way as in the corresponding Reservation Office. This applies to both origination of reservations and alteration of existing ones.

Passenger baggage processing has been influenced by the state of the aircraft technology. In 1961 when the manual (Firm N) and semi-automatic (Firm P) reservation systems were in use, the weight of baggage was needed to allow the load within the plane to be balanced. However, the subsequent deployment of larger aircraft on domestic flights (Firm N) reduced this requirement to the point where only tagging of the baggage to the appropriate destination is necessary.

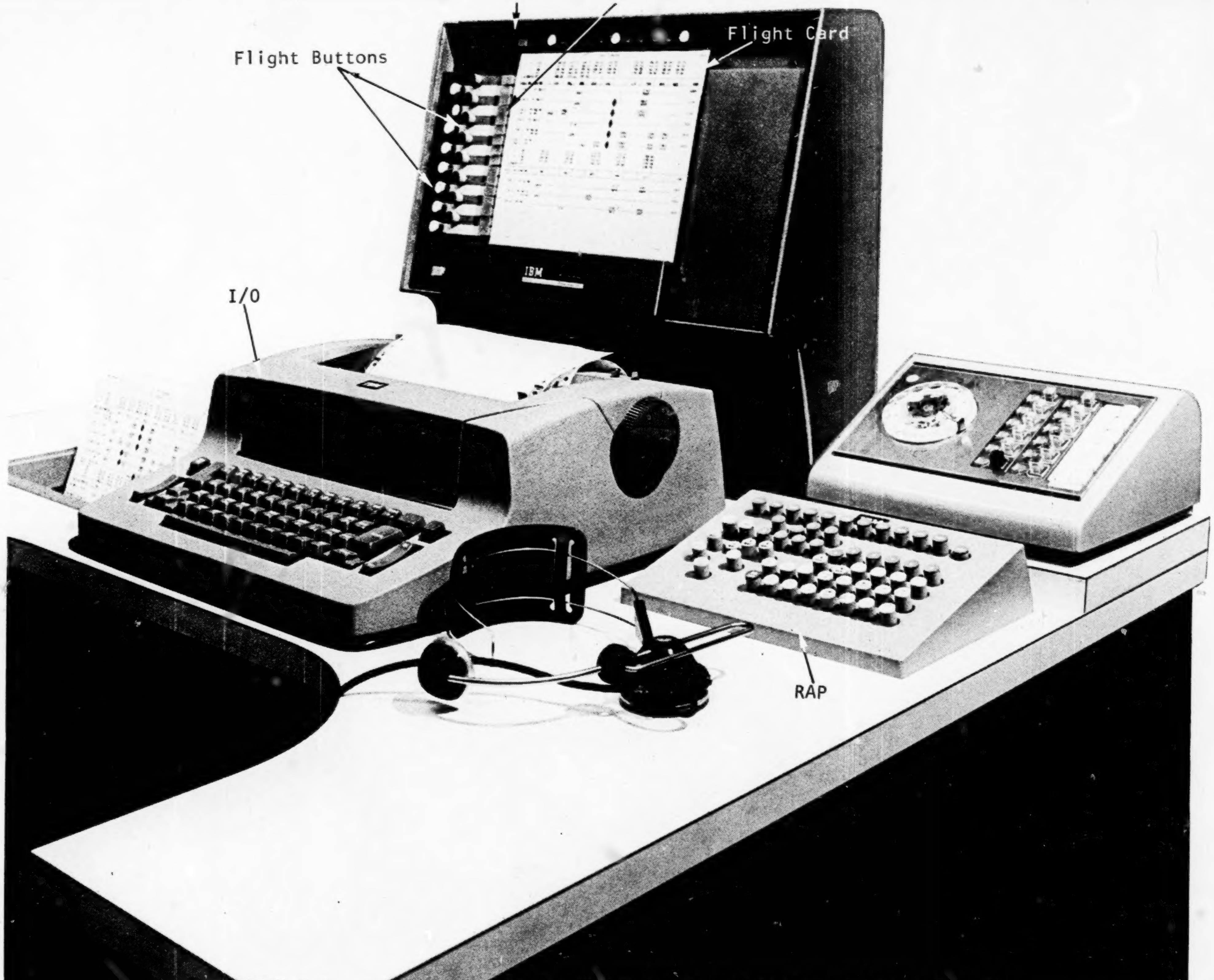
Flight Buttons
Flight Card
IBM
I/O
RAP

ILLUSTRATION F-2: AGENT SET USED IN COMPUTERIZED RESERVATION SYSTEMS (N2, P2)

Basic Functions	Passenger Service Technologies			
	Manual	Semi-Automatic	Computerized	
	Firm N	Firm P	Firm N	Firm P
1. Processing Reservations	Manual	Manual w/Agent Set	Agent Set	Agent Set
2. Checking Baggage	Tag and Weigh	Tag and Weigh	Tag	Tag and Weigh
3. Assigning Seats	Passenger Seat Selection	Assigned at Counter	Passenger Seat Selection	Assigned at Counter
4. Processing Information for Flight Reports and Special Services	Manual	Manual	Manual w/Computer	Manual

TABLE F-1: COMPARISON OF PASSENGER BOARDING PROCEDURES USED AT DIFFERENT TECHNOLOGICAL LEVELS.

On transoceanic flights load distribution remains critical and this accounts for the continued weighing of baggage at Firm P, an international carrier.

This same factor requires Firm P to assign seats to passengers at the counter in order to accomplish the proper distribution of the passenger and carry-on baggage portion of the total weight. Firm N, which has no such restrictions, allows passengers to choose their seat at the boarding gate.

The basic function of processing information for providing both internal reports and special passenger services involves obtaining pre-flight summaries of various types of data from the Passenger Reservation Records and compiling other summaries of post-flight data. In the manual and semi-automatic systems the information was communicated to and from the reservation control points via teletype with some control processing done at all points; the same occurs at Firm P even under the computerized technology. At Firm N however, the computer usurps some of the processing activities and the resulting lists are transmitted via the Agent Set to the proper location. In particular, the computer is used by the Ticket Lift Agent (Job Code N2-2f) to perform the following:

1. Preliminary Meal Ordering: Three hours before the scheduled departure of a flight a list is extracted which indicates the number of coach and first class meals which are required for passengers who have reserved seats up to that time. The orders which are transmitted via telautograph to the kitchen facilitate meal planning.
2. Final Meal Ordering and Special Services: A summary of special meal information such as dietary or kosher meals requested at the time of reservation is obtained. Also an up-to-date summary of coach and first class meal requirements to reflect late bookings is obtained one and one-half hours before departure. These are then communicated to the kitchen which changes the preliminary meal order. The special meal requests along with other passenger and flight information is recorded on a standard report form which is given to the stewardess so that the special in-flight services can be efficiently and accurately provided.
3. Post-Departure Leg and Load Reporting: Based on the actual number of boarded passengers of each class bound for each destination in the flight schedule, the number of seats available for subsequent legs of a flight (a leg is that portion of the flight from a take-off to the next landing) is updated to reflect booked passengers who did not show for boarding (noshos) and passengers who had no reservation records at the time of boarding (norecs). The load data which is entered into the computer allows reservation offices in cities where the flight is to land to make last minute bookings.
4. Post-Departure Reconciling: The flight coupons collected at the departure gate and an alphabetized name list, supplied by

the computer, of passengers (by class and destination) who have reserved seats are reconciled by the Ticket Lift Agent after the flight leaves the airport. "Noshos" are deleted, and "norecs" are added to bring the computer list up to date. The computer then performs a check by comparing the adjusted name list of passengers by class and destination to the load report (3 above) and any discrepancies which are printed out on the I/O typewriter are traced by the Ticket Lift Agent.

5. Statistical Reporting: A compilation of "noshos," "norecs," cancellations, and meal adjustments are entered into the computer.

Central Facilities

Of all the components of the passenger reservation system, it is the central facilities which have been most extensively transformed by the impact of technological changes. What even a very few years ago were slow and cumbersome record maintenance and processing centers have evolved into high speed nerve centers of the system, capable of dealing with ever increasing volumes of information in real time, i.e., responding within fractions of a second to incoming requests and data.

Under the manual system (Firm N) the function of the central facility was essentially one of seat inventory control. As each reservation for a particular class of seat on a particular flight was made at a local office and teletyped to Central Control, the number of available seats was correspondingly reduced until a predetermined level was reached. A message to this effect was then teletyped to the Reservation Offices. A large staff was required to perform this operation and the possibility of errors and confusion was ever present. In addition to the updating of seat inventories, wide discretion was exercised over the holding and releasing of blocks of seats.

The semi-automatic system (Firm P) incoroporated a central facility which consisted of a Reservation Control Group and a Central Processing group. The former performed the seat inventory control function described above. Central Processing, which was linked to all the Agent Sets in the country as well as to the Reservation Control Group, was equipped with a master control board and 38 flight racks. Each rack, about 7 feet high, 5 feet wide and 1 foot deep, was laid out with a matrix having up to 50 flight legs down the side and 31 days across the top. Thus, each cell of the matrix corresponded to a particular flight leg and date. In each cell were three jacks for indicating flight status--one representing "open seat" availability (i.e., sell and report), the second request status (i.e., request and reply), and the third the wait list--closed condition (i.e., no seats available but accept name so that a seat can be reserved in the event of a cancellation). Initially plugs were inserted in all the "open availability" jacks. When the Reservation Control Group, which updated the number of seats available as it received sell reports, found that the predetermined "cushion" had been reached for a particular flight, it notified a Central Processing Agent who inserted a plug in the "request" jack. When all seats were sold, Reservations Control again notified the Central Office and a plug was inserted in the "wait list-closed" plug.

When an electrical query from the Agent Set in the Reservations Office arrived at the master control board it was interpreted to identify the set of flights or flight legs and the date and was distributed to the corresponding cell. The nature of the response transmitted back to the Agent Set was determined by which jack in the cell contained the plug. Since up to about 50,000 cells had to be maintained, the main function of the personnel at the Central Office consisted of receiving status change notifications from Reservation Control and inserting plugs in the appropriate jacks.

Unlike the manual system in which passenger boarding was controlled from the control section of the local reservation office, the semi-automatic system used the Central Reservation Control Group to perform this function. It required the compilation of a passenger name list from the existing Passenger Reservation Records each of which was recorded on individual reservation cards. The list was then teletyped to the Airport Office at a particular time prior to flight departure.

The "nerve center" of the computerized technology is the central facility. In both Firm N and Firm P it consists of a complex interrelationship of computers and peripheral equipment (hardware) and programs (software) for accepting and processing messages. The main difference between the central facilities of the two firms is the existence of a Reservation Control group at Firm P, the reason for which is the international character of the service rendered. The group is needed to coordinate the activities of North American Offices (all of which have Agent Sets directly linked to the computer by high speed transmission lines) and Overseas Offices (most of which have no Agent Sets and are linked via teletype lines). The coordination consists of performing essentially the same function as under the semi-automatic technology -- updating of seat inventories and issuance of pre-departure passenger lists. The requirement for this coordination will diminish as the Overseas facilities become more compatible with those of North America. Even at this writing Agent Sets are being installed in major overseas offices and programs are being completed for implementation of the first of these functions on the computer.

The functions performed by Reservation Control are carried out with the aid of the computer. As the report of each sale is received, it is punched in code form on a paper tape. After several reports have been recorded, the tape is run through a tape-to-card converter which produces a card for each segment* of every passenger's flight. The cards, which are then sorted by segment, provide the basis for updating the seat inventories. In addition, a teletype tape is cut from the cards and is transmitted 6 hours before departure time to the airport where it prints out a passenger name list.

Firm N, all of whose offices are in North America, makes full use of the computer for updating seat inventories and for departure processing (see preceding discussion of Airport Office).

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*A flight segment is that portion of a passenger's flight from boarding to deplaning. Thus a passenger's itinerary can consist of one or more segments.

Besides the Reservation Control group, Firm P maintains a central EDP system which is very similar to that of Firm N. Each aspect of the system -- real time characteristics, hardware, software, use of memory storage, and interline processing procedures -- is comparable in both firms, and therefore, the description of the state of the technology in one firm is sufficient to obtain an understanding of the nature of the EDP system. Thus, the specifics of the first four aspects apply to Firm P while the details of the interline processing procedure refer to Firm N.

Real Time Characteristics -- Messages arrive from Agent Sets and teletypes at random times and vary in length and nature. In addition, the sequence of operations required to process these messages is unpredictable. Despite these non-repetitive cycles of events, several transactions must be in the computer at once to fully utilize the systems capability to handle the large volume and variety of messages received. This time sharing process is controlled by a program which is described in the discussion of software.

Hardware -- The equipment comprising the duplexed data processing system consists of IBM 7750 programmed transmission control units, IBM 7080 data processing systems, drum files, and disc files. The 7750 assembles and prepares messages entering and leaving the 7080 system. In addition to a standby unit, there is a second 7750 for accepting high speed line messages, and a third 7750 for messages coming from the low speed teletype lines. Two 7080's are used one at a time for on-line processing of messages originating from Agent Sets. The second unit performs off-line processing, consisting of updating of files for on-line use, future program testing and preventive maintenance. The core memory of the system which contains 4 storage units holds 480,000 characters. Access time is of the order of one millionth of a second. This is supplemented by several drum and disc files. Each drum file which is a magnetic storage device has a capacity of 1 million characters and an access time of 8-10 milliseconds. The random access disc files has a 50 million character capacity and a 50-180 millisecond access time.

Software -- The complexity of the reservation system requires hundreds of programs to process the variety of information generated. Control of seat inventory, maintenance and retrieval of passenger records, compiling lists of information selected from various records, are only a few of the functions performed by the system. The programs which accomplish this can be categorized into three main types -- on-line, off-line, and control.

The main function of the on-line or operational programs is to provide real time processing of messages from Agent Sets and teletype sets. There can be as many as 500 of these programs, each one being used for a particular processing activity such as updating the seat inventory of a flight after a sale or cancellation, accepting a passenger record and transferring it to the appropriate drum or disc file, obtaining all or part of a passenger record from one of these files for transmission back to the agent or for making a change in it, and searching flights for a particular passenger record.

Off-line programs prepare or change existing files. This includes changes of flight schedules, preparation of files for reception of on-line records, and preparation of lists of information obtained from several passenger records (i.e., passenger name lists by class of service, special facts lists, ticket option lists, etc.). For example, in Firm N, if no indication is received from the Agent Set that a ticket has been picked up within the time limit specified in the PRR, the space is automatically cancelled (except for long itineraries).

The control programs regulate the order and priority in which information is processed by inspecting each input and calling into use the appropriate operational program. The control program also makes possible the time sharing of the computer and the various components of the system. For example, when a stored record is needed to complete the processing of a particular input, the operational program requests the record from the drum or disc storage. During the time required to obtain this record, the control program causes the computer to move on to some other item awaiting processing, while preserving the transaction in process. When the required record has become available for use by the operational program, the control program will reactivate the processing of the preserved transaction. Upon completing this transaction, the operational program signals the control program which arranges to send the answer back to the originator and also returns any records to the appropriate storage file.

Other control program functions include monitoring of the amount of core storage available, controlling activity of off-line programs, providing for communication between active and standby computers, identifying lags, and resolving errors.

Use of Memory Storage -- As mentioned previously, both drum and disc files are utilized for storage of records. The drum file, with its fast access time, is used to store records which are referred to frequently. Examples of these are: 1) commonly used operational programs and 2) seat availability records for flights departing within a short period of time.

The disc file, whose access time is about 10 times that of the drum file, is used for 1) seat availability records for flights departing in the more distant future and 2) for passenger reservation records. The latter take up about 80 percent of the disc file capacity.

Interline Processing Procedures -- Interline transactions which previously required many separate messages and communications have been greatly simplified. In Firm N for example, any segment of a trip which involves connection with another airline is entered into the Agent Set. The message is then compiled in accordance with the standard interline machineable message format including the proper address and code directing characters and sent to the other airline via the communications system. If an answer is not received within a specified period of time, a follow-up reply request is automatically initiated by the system. When the answer is received the PRR is automatically brought up to date and sent to the city in control of the passenger so that he can be contacted if necessary.

Communications Network

The entire communications network utilized with the manual system consisted of teletype lines extending between the local offices and central control. This was augmented in the semi-automatic system by the network of links between Agent Sets and the Central Office. Several Agent Sets in one location were connected locally to a central point which was in turn linked via telephone wires to the master control board.

The advent of the computerized passenger service system required a much more complicated and extensive network of communication facilities to connect all the agent sets throughout the country to the Central Electronic Data Processing System. The equipment utilized by Firm P to connect the Agent Set to the Central EDP is very similar to Firm N's and is represented in Figure F-1.

A remote Agent Set transmits serial binary data to a data subset which converts (modulates) it to voice frequency tones and sends it over low speed (about 100 bits per second) telephone transmission lines to another data subset which reverses the process (demodulates) and sends the binary data to a terminal interchange (TI). Agent Sets on the same premises as the TI transmit directly by cable without the use of subsets. About 30 agent sets are connected to each terminal interchange which assembles and stores messages. Installed at the TI is a data subset which multiplexes and modulates the stored information and sends it over high-speed (2700 words per minute) transmission lines to another demodulating data subset at the EDP Center. The data entering the EDP system comes from this data subset. The whole process is reversed for data going from the EDP Center to an Agent Set.

The network of teletypes maintained by Firm P is connected to the Central EDP as shown in Figure F-2 . Teletypes throughout the country are tied into a central electronic switching device which routes incoming messages to the proper location, whether they are other teletypes or the Central EDP. About 75,000 incoming and 85,000 outgoing messages are handled each day.

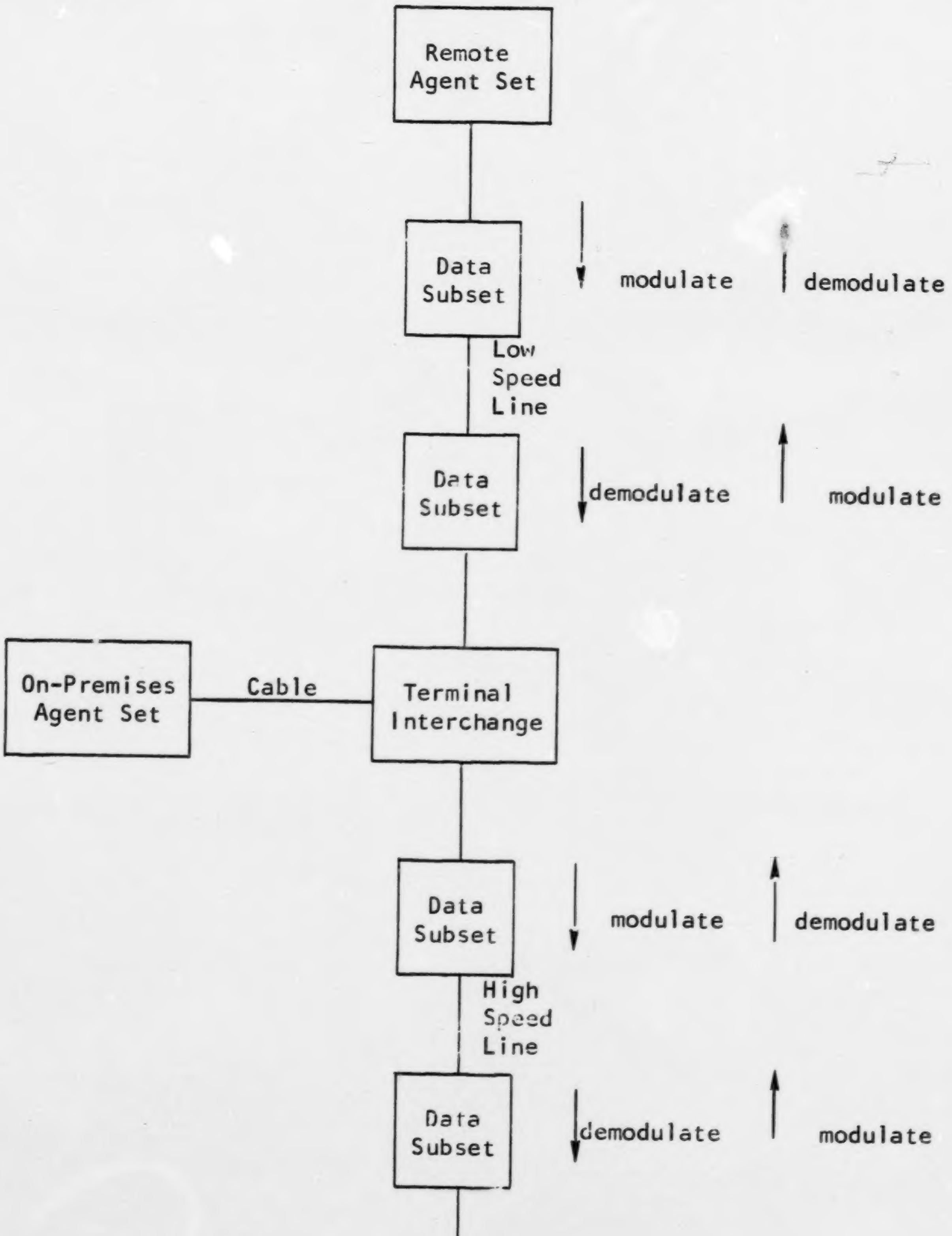
Remote Agent Set
Data Subset
modulate
demodulate
Low Speed Line
Data Subset
demodulate
modulate
On-Premises Agent Set
Cable
Terminal Interchange
Data Subset
modulate
demodulate
High Speed Line
Data Subset
demodulate
modulate
To EDP System

FIG. F-1: COMMUNICATION LINKS BETWEEN AGENT SET AND EDP SYSTEM IN COMPUTERIZED TECHNOLOGY (N2, P2)

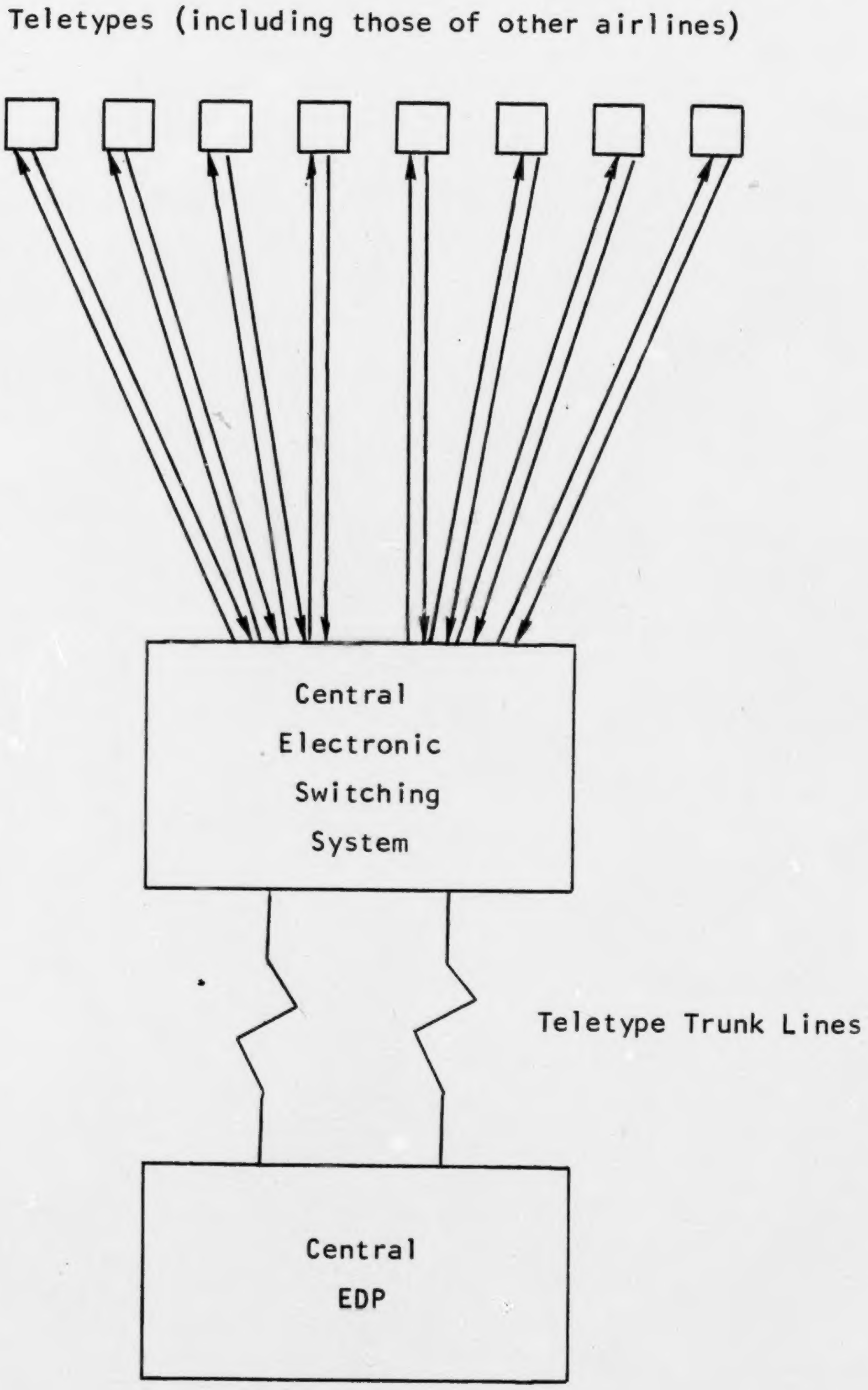
Teletypes (including those of other airlines)
Central Electronic Switching System
Teletype Trunk Lines
Central EDP

FIG. F-2: COMMUNICATION LINKS BETWEEN TELETYPES AND EDP SYSTEM IN COMPUTERIZED TECHNOLOGY (N2, P2)

2. INFORMATION FLOW AT EACH TECHNOLOGY LEVEL

Manual Systems

In the earliest manual system known as the "Request and Reply" System, the Reservation Agent had to initiate a teletype message to find out if space was available every time a customer requested a seat. The resulting large number of communications required made this system very slow and led to its replacement by the "Sell and Report" system which is described below and represented diagramatically in Figure F-3.

The booking process is initiated by the customer (designated by the "x" on the customer block) who calls the Reservation Office (1) to inquire about flight availability and schedules. The Reservations Agent confirms a seat on the selected flight (2) and records reservation information pertaining to the passenger (3) on a card. This passenger reservation record (PRR) is sent to the local control section of the reservation office (4). If the reservation is for a flight departing from an airport in another city, the PRR is teletyped to the reservation office there (5). On the other hand, if a flight departs from the local airport, the PRR is filed along with other reservations for that flight, including those made at other reservation offices(6). The local control agent reports the reservation to Central Control (7) which keeps track of the number of seats sold on all flights. When all but a few seats on a particular flight have been sold, Central Control sends a "Stop Sale" message to all Reservation Offices (8) via teletype. This lower-than-capacity limit is established to cushion the effect of reports of reservations which might be enroute from local control to Central Control during the period that the stop sale message is en route from Central Control to local control. After a particular flight has been put on stop sale, the Reservation Agent reverts to the Request and Reply system to secure space on that flight. When all seats have been sold on the flight, central control transmits a "closed" message to the Reservation Offices (8). A board at the front of the Reservation Office is used to indicate the current daily status of high activity flights (usually local departures) leaving during the following month. When a flight is requested by a customer, the Reservation Agent looks at this board to determine if the flight is open (i.e., "Sell and Report"), partly closed (i.e., "Request and Reply"), closed (i.e., put on wait list or suggest another flight) or not scheduled (i.e., suggest another flight).

If the customer chooses to pick up his ticket at a Ticket Office, local control sends itinerary, rate, passenger and other ticketing information to the Ticket Office (9) which issues the ticket to the customer (10). Prior to the departure of a particular flight, local control teletypes a passenger list, meal order, and other pre-flight information to the airport (11). When the customer arrives at the airport, he is checked in and his ticket coupon is collected (12). After the flight departs, the coupons received are reconciled with the passenger list. Passenger statistics are then compiled and sent to the appropriate destinations (13).

Although variations in the information flow can occur, they do not significantly alter the process. When a customer makes a reservation at the airport, the Reservation Agent there follows the same procedure used at the Reservation Office. Similarly, when a ticket is obtained at the airport, the same course of action is followed as at the other ticket offices. Also, space for connecting passengers can be secured at other airlines by means of a teletype link between offices of the airlines.

The customer may call to obtain other information than that pertaining to flight schedules. In this case, the Reservation Agent provides the information by contacting local Reservation Control in his own Reservation Office, teletyping the control section of another Reservation Office, or teletyping Central Reservation Control. The source of information depends on the nature of the customer inquiry, but in any event, teletype provides the main communication link for most transactions.

Semi-Automatic Systems

Semi-automatic systems like manual systems require close coordination between Reservation Offices and the Central Reservations Control unit. However, this coordination is accomplished through the use of a central electro-mechanical processor which stores and transmits seat availability information. The flow of information between the elements providing passenger reservation service is represented diagramatically in Figure F-4.

The customer secures a seat by initiating (see "x" on border of customer's box) a phone call to the Reservations Office to obtain flight schedule information (1). After determining the particular flight desired by the customer, the Reservation Agent inserts a small notched metal plate into the "reader" part of his Agent Set. The notches which identify the flight (and flight legs) labelled on the plate are sensed and this identity is transmitted to the central processor (2). The aforementioned communication is in effect an inquiry regarding seat availability because a flight status reply is received (3) which indicates by lights on the Agent Set whether a flight is closed or open. Thus, the Reservation Agent is able to give a prompt reply (4) to the customer who, when wishing to make a booking, supplies his name, address and other reservation information (5). As with the manual system, the agent records this information on a card after which it is teletyped to the Central Reservation Control unit (6). This unit receives reservation information from all Reservation Offices and keeps an inventory of the number of seats sold on each flight. When all seats have been sold for a particular flight, Central Control advises the central processor unit to close the flight (7). The closing is accomplished by inserting a plug in the proper jack on a master control board having jacks for each flight, leg (segment of a flight), and date. This, in turn, determines the state of the light indicator on the Agent Sets in all Reservation Offices.

When a customer picks up the ticket, the relevant information obtained from the Passenger Reservation Record filed in the Reservation Office

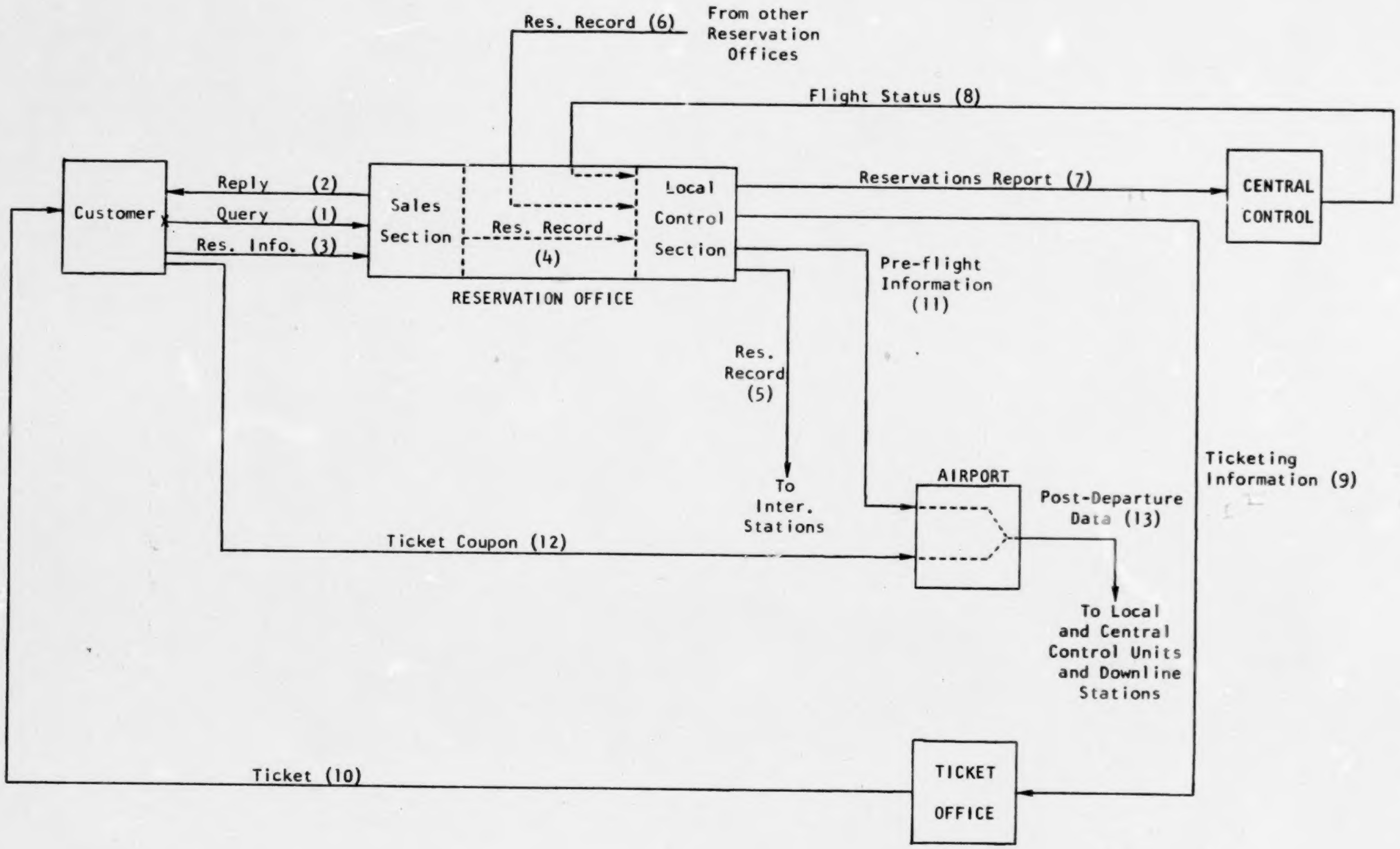
Res. Record (6)
From other Reservation Offices
Flight Status (8)
Customer
Reply (2)
Query (1)
Res. Info. (3)
Sales Section
Res. Record (4)
Local Control Section
RESERVATION OFFICE
Reservations Report (7)
CENTRAL CONTROL
Pre-flight Information (11)
Res. Record (5)
To Inter. Stations
AIRPORT
Post-Departure Data (13)
To Local and Central Control Units and Downline Stations
Ticketing Information (9)
Ticket Coupon (12)
Ticket (10)
TICKET OFFICE

FIGURE F-3: INFORMATION FLOW IN MANUAL "SELL AND REPORT" RESERVATION SYSTEM (N1)

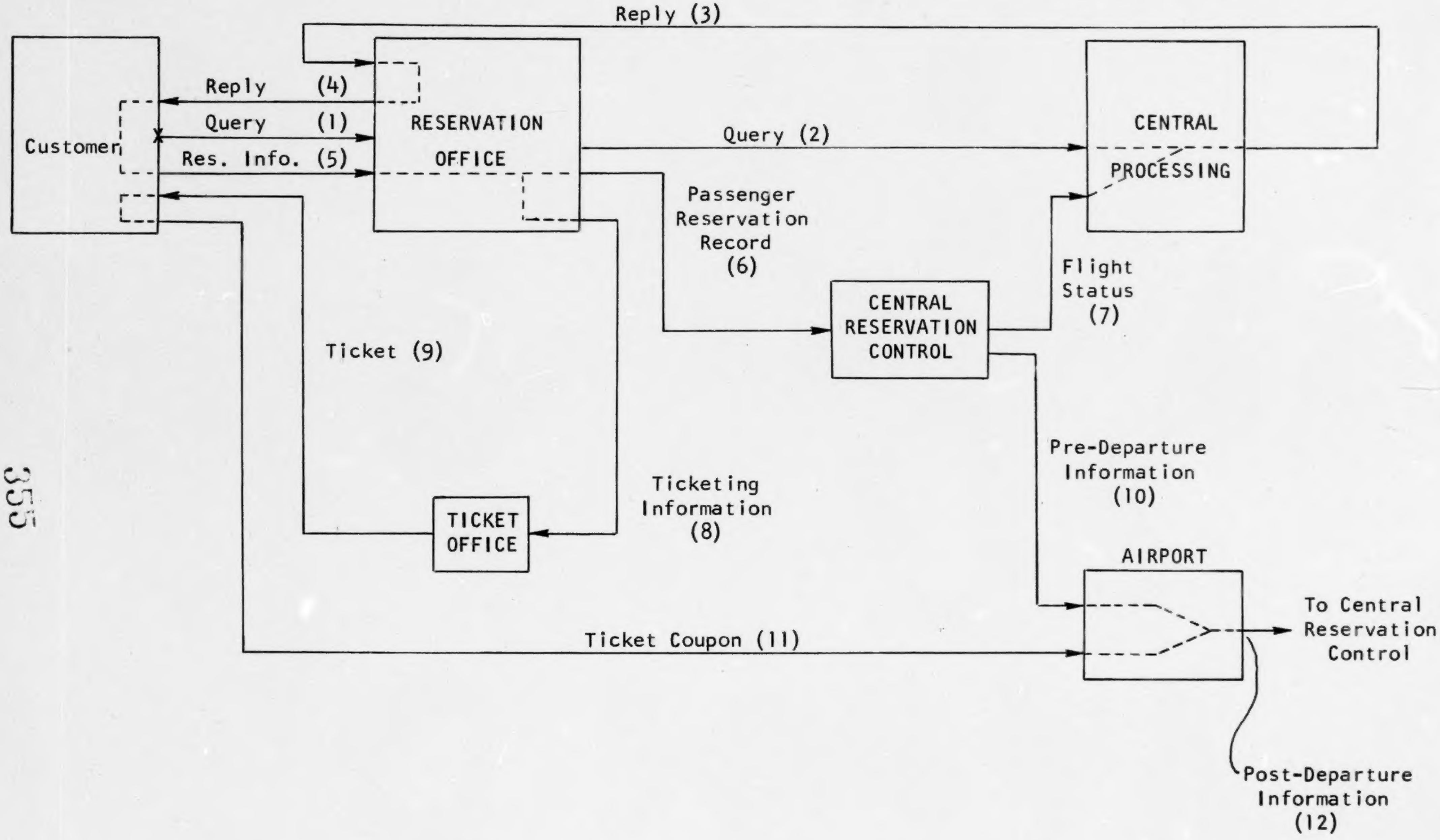
Reply (3)
Customer
Reply (4)
Query (1)
Res. Info. (5)
RESERVATION OFFICE
Query (2)
CENTRAL PROCESSING
Passenger Reservation Record (6)
CENTRAL RESERVATION CONTROL
Flight Status (7)
Ticket (9)
Pre-Departure Information (10)
Ticketing Information (8)
TICKET OFFICE
AIRPORT
To Central Reservation Control
Ticket Coupon (11)
Post-Departure Information (12)

FIG. F-4: INFORMATION FLOW IN SEMI-AUTOMATIC RESERVATION SYSTEM (P1) is communicated to the Ticket Office (8) which issues the ticket (9). A short time prior to the boarding of the aircraft, a predeparture communication consisting of meal, loading, and passenger information is sent to the airport from Central Control (10). Part of this is used to provide passenger service and the rest is reconciled with the ticket coupon collected from the passenger at the airport (11). A post-departure report regarding number of passengers boarded, "noshos" (customers holding reservations, but not boarding), "norecs" (boarded passengers who did not appear on pre-departure passenger list), etc. (12) is compiled and sent to Central Reservation Control.

When a reservation is made or a ticket collected at the airport, the same procedure is followed as at the Reservation Office. The Reservation Agent utilizes manual files and records or initiates a teletype inquiry to provide passenger, fare, schedules of other airlines, etc.

Computerized System

The main flow of information in a typical computerized reservation system is shown diagramatically in Figure F-5. The flow represents the most common sequence of transactions, from the booking of a customer's reservation to his departure on the specified flight.

The process is initiated by the customer (see "x" on boundary of customer block) who calls the Reservation Office with a query (1) regarding flights for which he might obtain a reservation. The Sales Agent who receives the call uses a prescribed format to communicate the query to the computer (2) via special typewriter. A common type of query refers to the availability of seats on a given flight. The EDP determines the proper reply and transmits it back to the Agent's Input/Output typewriter (3). The Agent relays the reply to the customer (4) and on the basis of this information the customer makes a reservation (5). To complete the reservation transaction, the Agent elicits the customer's name, address, and all other relevant information which constitutes the Passenger Reservation Record, types it directly into the Input typewriter, and sends it to the EDP (6) by depressing a specified button. This entry causes the PRR to be filed on a disc until such time as it is needed, and simultaneously reduces the inventory of seats still available by one.

When the customer arrives at the Ticket Office to obtain his ticket, the Sales Agent retrieves from the central disc file the portion of the Passenger Reservation Record required for ticketing (7) and prepares the flight ticket which is given to the customer(8). The next transaction occurs at a specified time prior to the departure of a flight. The Passenger Service Agent retrieves a compilation of information (9) which the computer has assembled from the records of all passengers who have reserved space on that flight; this includes a list of passenger names, the number of meals required for each class of service, and any other special requests, such as special meals, wheel chairs, or infant facilities which the Passenger Service Agent passes on to personnel responsible for providing these services. Next, he collects the proper flight coupon from the passenger's tickets at the boarding point (10). After departure of the flight, the Agent reconciles the passenger list prepared by the computer with the ticket coupons collected at boarding. He then transmits a post-departure report (11) containing various flight statistics, such as the number of passengers boarding for each class of service and the number of customers who had made reservations but did not utilize them (noshos).

Several variations can occur in the flow of transactions shown. For instance, the customer may make a reservation at either the Ticket Office or the airport instead of the Reservation Office. However, the Customer-Agent and the Agent-EDP transactions are the same at all three locations. Similarly, the ticket may be issued at the airport or mailed to the customer in which case the same ticketing procedure is used as at the Ticket Office. Also, space for connecting passengers can be reserved by other airlines through a hook-up which exists between central EDP's; the corresponding Passenger Reservation Records are entered via teletype and transmitted to the central EDP, where they are stored along with all other flight records. Transactions (9) - (11) then occur as above.

The system described here is common to both Firm N and Firm P with one exception. Instead of the computer, Firm P employs a Central Reservation Control Section to maintain the seat availability inventory and the Reservations Office Agent merely receives a "flight open/closed" message.

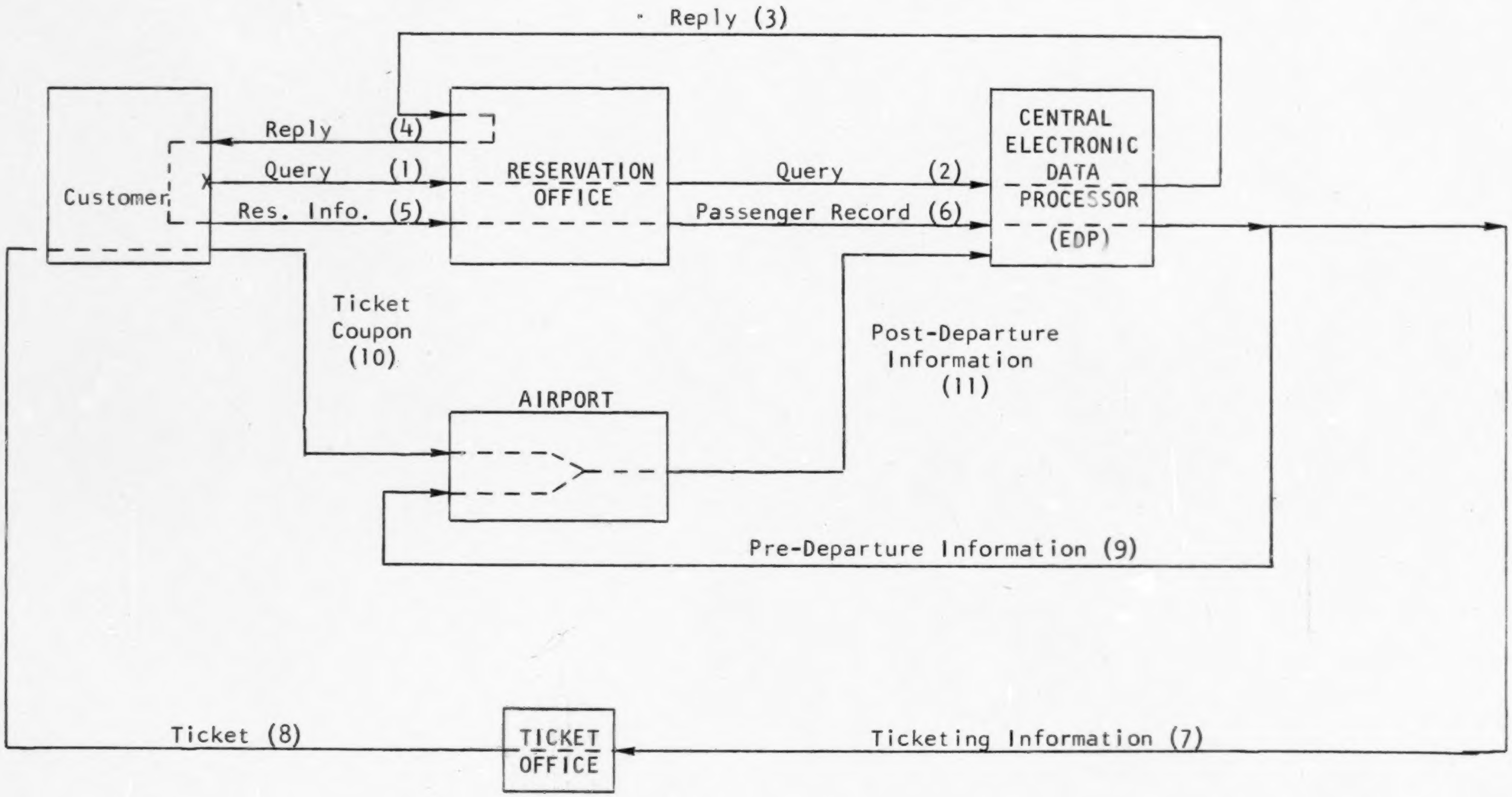
Reply (3)
Customer
Reply (4)
Query (1)
Res. Info. (5)
RESERVATION OFFICE
Query (2)
Passenger Record (6)
CENTRAL ELECTRONIC DATA PROCESSOR (EDP)
Ticket Coupon (10)
AIRPORT
Post-Departure Information (11)
Pre-Departure Information (9)
Ticket (8)
TICKET OFFICE
Ticketing Information (7)

FIG. F-5: INFORMATION FLOW IN COMPUTERIZED RESERVATION SYSTEM (N2, P2)

3. METHOD OF DERIVING SKILL LEVEL VALUES FROM JOB EVALUATION SCHEMES

Airline N

The job evaluation scheme is applied to non-management salaried jobs and has been in use for several years prior to the introduction of the EDP system. The following seven factors, each having several degrees with corresponding point values, make up the plan:

1. Training and experience
2. Initiative and Supervision Received
3. Mental application
4. Responsibility for accuracy
5. Contacts
6. Physical effort
7. Working conditions

In the study the point ratings of factors 1, 3 and 5 have been totaled to obtain skill level values. These factors are defined as follows:

> TRAINING AND EXPERIENCE "considers the knowledge and background required to do a job. It measures skill, specialized knowledge, education and working experience. These measurements are affected by complexity of the duties to be performed."
>
> MENTAL APPLICATION "considers those job activities that cause mental fatigue. It measures the difference in demands on thought processes such as judgement, concentration demands and pressures. These measurements are affected by both intensity and duration."
>
> CONTACTS "considers the job requirements for relationships with others. It measures the differences in such activities as telephone, personal, and written contacts and the purpose of contacts. These measurements are affected by the difficulty and frequency of contacts."

The range of points and the number of discrete point values that each factor can assign to a job are as follows:

	No. of Possible Values	Range
Training and experience	6	25-250
Mental application	9	15-200
Contacts	9	12-150

Airline P

Skill ratings for Airline P jobs were estimated by its management personnel using Airline N's job evaluation plan.

4. DERIVATION OF VOLUME DATA (Passengers/Month)

Manual System N1

Reservations Office Airport Ticket Offices City Ticket Offices	Average of 24 monthly volumes of passengers boarded on flights originating from San Francisco and Oakland during 1960-1961
Area Control	Average of 24 monthly volumes of passengers boarded on all flights of the airline during 1960-1961

Computerized System N2

Reservations Office Airport Ticket Offices City Ticket Offices	Average of 21 monthly volumes of passengers boarded on flights originating from San Francisco and Oakland during 1965-1966
EDP Operations	Average of 21 monthly volumes of passengers boarded on all flights of the airline during 1965-1966

Semi-Automatic System P1

Reservations Office Ticket Office Airport Office	Average of 12 monthly volumes of passengers boarding flights in San Francisco during 1961
Reservations Control Central Processing	Average monthly volume of passengers boarded on all flights of the airline during 1961 (based on yearly figure provided in annual report)

Computerized System P2

Reservations Office Ticket Office Airport Office	Average of 12 monthly volumes of passengers boarding flights in San Francisco during 1966
Reservations Control EDP Center	Average monthly volume of passengers boarded on all flights of the airline during 1966 (based on yearly figure provided in annual report)

5. DERIVATION OF MANHOUR DATA (Hours Worked/Month)

Manual System N1

Reservation Office	Number of people employed in San Francisco Reservation Office on January 15, 1961 (Obtained from available records)
Airport Ticket Offices City Ticket Offices	Average number of people employed during 1960-1961 (Estimated by airline management personnel)
Area Control	Number of people employed at Central controlling location on Jan. 15, 1961 (Obtained from available records)

Computerized System N2

Reservations Office Airport Ticket Office	Average of number of people employed monthly for 21 month period during 1965-1966 (Obtained from both actual records and management estimates)
City Ticket Office	Number of people employed on December 31, 1966 (Obtained from both actual records and management estimates)
EDP Operations	Number of people employed on December 15, 1966 (Obtained from both actual records and management estimates)

Semi-Automatic System P1

Reservation Office Ticket Office	Average of 1961 monthly manpower utilization reports (Where required, prorating done by management personnel)
Airport Office	Average 1961 labor utilization (Estimate made by company management personnel)
Reservations Control	Average 1961 labor utilization (Obtained from both actual records and management estimates)
Central Processing	Average 1961 labor utilization (Obtained from both actual records and management estimates)

Computerized System P2

Reservation Office Ticket Office	Average of 1966 monthly manpower utilization reports
Airport Office	Average of 1966 biannual manpower utilization reports
Reservations Control	Average 1966 manpower utilization (Obtained from available records and management estimates)
EDP Center	Average 1966 manpower utilization (Obtained from available records and management estimates)

6. RAW DATA USED FOR SKILL PROFILES

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
N1 MANUAL PROCESSING				
Reservation Office (Volume: 19,000 Passengers/Month)				
N1-1a	203.558	Teletype Operator A	138	693.3
N1-1b	203.558	Teletype Operator B	138	520.0
N1-1c	202.388	Stenographer-Clerk	158	173.3
N1-1d	206.338	Records Clerk	165	173.3
N1-1e	235.862	Telephone Operator	190*	866.7
N1-1f	235.138	Lead Telephone Operator	190*	173.3
N1-1g	203.138	Lead Teletype Operator A	190	173.3
N1-1h	201.368	Secretary	231*	173.3
N1-1i	912.368	Reservations Salesman	265	6066.7
N1-1j	912.368	Part-Time Reservation Salesman	265	520.0
N1-1k	912.368	Reservations Control Agent	280	5720.0
N1-1l	912.368	Reservations Control Agent	306	1040.0
Airport Office (Volume: 19,000 Passengers/Month)				
N1-2a	912.368	Ticket Lift Agent	262**	1386.7
N1-2b	919.368	Passenger Service Representative	265	693.3
N1-2c	912.368 919.368	Ticket Salesman	385	2426.7
City Ticket Office (Volume: 19,000 Passengers/Month)				
N1-3a	201.368	Secretary	231*	173.3
N1-3b	919.368	Ticket Salesman	360	2808.0***
Central Control Group (Volume: 675,827 Passengers/Month)				
N1-4a	201.368	Secretary	231*	173.3
N1-4b	912.368	Reservations Control Agent	280	11960.0
N1-4c	912.368	Reservations Control Agent	306	346.7
N2 COMPUTER PROCESSING				
Reservations Office (Volume: 28,045 Passengers/Month)				
N2-1a	203.558	Teletype Operator	138	173.3
N2-1b	206.338	Records Clerk	165	173.3
N2-1c	235.862	Telephone Operator	165*	386.5
N2-1d	201.368	Secretary	231*	173.3
N2-1e	912.368	Reservation Service Agent	261	1196.0

N2 COMPUTER PROCESSING (Cont'd)

Job Code	Job D.O.T. No.	Job Title	Skill Level	Manhours Per Month
Reservations Office (Cont'd)				
N2-1f	912.368	Reservation Salesman	280	6957.6
N2-1g	912.368	Part-Time Reservation Salesman	280	197.6
N2-1h	912.368	Reservation Service Agent	325	906.5
Airport Office (Volume: 28,045 Passengers/Month)				
N2-2a	201.368	Secretary	231*	173.3
N2-2b	919.368	Passenger Service Representative	265	592.8
N2-2c	919.368	Utility Agent	265**	395.2
N2-2d	919.368	Domestic Arrival Salesman	265**	147.3
N2-2e	912.368 919.368	Ticket Salesman	385	3705.9
N2-2f	912.368	Ticket Lift Agent	387**	2508.1
N2-2g	912.368	Baggage Service Agent	472**	386.5
N2-2h	919.368	Departure Salesman	500**	173.3
City Ticket Offices (Volume: 28,045 Passengers/Month)				
N2-3a	201.368	Secretary	231*	208.0
N2-3b	919.368	Ticket Salesman	360	3344.7***
EDP Operations (Volume: 1,042,206 Passengers/Month)				
N2-4a	237.368	Receptionist	158*	173.3
N2-4b	206.338	Records Clerk	165*	173.3*
N2-4c	213.582	Key Punch Operator	177	346.7
N2-4d	201.368	Secretary	231*	173.3*
N2-4e	213.382	Console Operator	450	1733.3
N2-4f	219.388	EDP Service Agent	450	346.7
N2-4g	213.382	Senior Console Operator	450*	520.0
N2-4h	020.188 219.388	Programmer Technician	485*	173.3
N2-4i	020.188 219.388	Programmer	485*	866.7
N2-4j	020.168	Senior Programmer	515*	173.3
N2-4k	012.168	Senior Systems Analyst	550*	346.7

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* Estimated by Researchers

** Estimated by Management and Supervisory Personnel

*** These manhours include secretary and supervisor time spent as ticket salesman.

P1 SEMI-AUTOMATIC PROCESSING

Reservation and Ticket Office (Volume: 8,100 Passengers/Month)

Job Code	Job D.O.T. No.	Job Title	Skill** Level	Manhours Per Month
P1-1a	231.588	Mail Clerk	85	173.3
P1-1b	235.862	Telephone Operator	85	329.3
P1-1c	206.338	File Supervisor	85	173.3
P1-1d	919.368	City Check-In Agent	110	364.0
P1-1e	203.558	Teletype Operator	110	676.0
P1-1f	211.368	Cashier	126	571.9
P1-1g	912.368	Tourist Card Preparation Agent	146	156.0
P1-1h	912.368	Domestic and Interline Desk Agent	146	398.7
P1-1i	201.368	Secretary	155	173.3
P1-1j	206.338	Central File Agent	161	1178.6
P1-1k	201.368	Passenger Reservations Correspondence Agent	165	294.7
P1-1l	912.368	Telephone Sales Agent/ Agency - II	200	1248.0
P1-1m	919.368	Prepaid Sales Agent	225	242.7
P1-1n	912.368	Telephone Sales Agent/ Agency - I	243	520.0
P1-1o	912.368	Telephone Sales Agent/Direct	288	1473.3
P1-1p	912.368	Telephone Sales Agent/ Commercial	288	398.7
P1-1q	912.368	Group Sales Agent	313	901.3
P1-1r	919.368	Rates and Ticketing Agent	318	710.7
P1-1s	919.368	Counter Sales Agent	343	1317.3

Airport Office (Volume: 8,100 Passengers/Month)

Job Code	Job D.O.T. No.	Job Title	Skill** Level	Manhours Per Month
P1-2a	912.368	Baggage Representative	190	520.0
P1-2b	201.368	Secretary	250	173.3
P1-2c	912.368 919.368	Passenger Service Representative	315	1386.4
P1-2d	912.368 919.368	Sales Agent	315	520.0
P1-2e	912.368	Concourse Supervisor	365	520.0
P1-2f	912.368	Counter Supervisor	387	520.0
P1-2g	912.368	Load Control Supervisor	420	520.0

Central Reservations Control Office (Volume: 316,250 Passengers/Month)

Job Code	Job D.O.T. No.	Job Title	Skill** Level	Manhours Per Month
P1-3a	201.368	Secretary	231*	693.3
P1-3b	912.368	Control Agent	280*	25128.5

P1 SEMI AUTOMATIC PROCESSING (Cont'd)

Central Processing Office (Volume: 316,250 Passengers/Month)

Job Code	Job D.O.T. No.	Job Title	Skill** Level	Manhours Per Month
P1-4a	912.368	Sales Agent - II	161*	346.7
P1-4b	912.368	Sales Agent - I	181*	346.7

P2 COMPUTERIZED PROCESSING

Reservation and Ticket Office (Volume: 15,500 Passengers/Month)

Job Code	Job D.O.T. No.	Job Title	Skill** Level	Manhours Per Month
P2-1a	231.588	Mail Clerk	85	173.3
P2-1b	235.862	Telephone Operator	85	346.7
P2-1c	203.558	Teletype Operator - II	85	202.2
P2-1d	201.368	Passenger Reservation Correspondence Agent - II	85	223.8
P2-1e	912.368	Destination Card Preparation Clerk	85	173.3
P2-1f	919.368	Ticket Preparation Agent	103	765.4
P2-1g	203.558	Teletype Operator - I	110	173.3
P2-1h	919.368	City Check-In Agent	110	242.6
P2-1i	211.368	Cashier	126	294.6
P2-1j	912.368	Domestic Desk Agent	146	332.2
P2-1k	201.368	Secretary	155	173.3
P2-1l	912.368	Sales Service Agent - II	161	918.5
P2-1m	201.368	Passenger Reservation Correspondence Agent - I	165	173.3
P2-1n	912.368	Sales Solicitation Agent	190	173.3
P2-1o	919.368	Refund Desk Agent	200	164.6
P2-1p	919.368	Prepaid Sales Agent	215	397.1
P2-1q	912.368	Telephone Sales Agent/Direct and Agency - II	243	4003.2
P2-1r	201.368	Reservations Coordinator	245	173.3
P2-1s	912.368	Sales Service Agent - I	263	173.3
P2-1t	912.368	Telephone Sales Agent/Direct and Agency - I	313	520.0
P2-1u	912.368	Group Sales Agent	313	937.3
P2-1v	912.368	Telephone Sales Agent/Commercial	313	527.1
P2-1w	919.368	Counter Sales Agent	343	1597.2
P2-1x	919.368	Rate Quotation Agent	365	446.2
P2-1y	919.368	Travel Consultant	390	346.7

Airport Office (Volume: 15,500 Passengers/Month)

Job Code	Job D.O.T. No.	Job Title	Skill** Level	Manhours Per Month
P2-2a	912.368 235.862	Clerk	145	520.0
P2-2b	202.388	Clerk Stenographer	181	173.3
P2-2c	919.368	Employee Ticket Representative	225	433.3
P2-2d	201.368	Secretary	250	173.3

P2 COMPUTERIZED PROCESSING

Job Code	Job D.O.T. No.	Job Title	Skill[**] Level	Manhours Per Month
Airport Office (Cont'd)				
P2-2e	919.368	Receptionist	252	260.0
P2-2f	912.368	Load Control Representative	270	173.3
P2-2g	912.368	Baggage Representative	290	606.6
P2-2h	919.368 912.368	Passenger Service Representative	315	3639.3
P2-2i	919.368	Special Services Supervisor	340	520.0
P2-2j	919.368 912.368	Sales Agent	360	520.0
P2-2k	912.368	Counter Supervisor	387	693.2
P2-21	912.368	Load Control Supervisor	420	520.0
Central Reservation Control Office (Volume: 608,600 Passengers/Month)				
P2-3a	201.368	Secretary	231[*]	866.5
P2-3b	912.368	Control Agent/Message Center	250[*]	24608.6
P2-3c	912.368	Control Agent	280[*]	2252.9
Central Electronic Data Processing Center (Volume: 608,600 Passengers/Month)				
P2-4a	206.338	Schedule Clerk	165	867.0
P2-4b	213.582	Key Punch Operator	177	87.0
P2-4c	201.368	Secretary	231	173.0
P2-4d	213.382	Tape Changer	450	728.0
P2-4e	213.382	1401 Operator	450	728.0
P2-4f	213.382	Console Operator	450	364.0

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[*] Estimated by Researchers.

[**] All skill level values in this column estimated by company management personnel unless otherwise indicated.

7. DETAILED SUMMARY OF STATISTICAL TREATMENTS USED

a) "t"-Test for Differences between Mean Skill Levels

A full tabulation is given of technologies and their corresponding mean skill levels and variances (σ^2). Next the rises in mean skill level are shown, followed by the calculated value of "t", the degrees of freedom (D.F.) and the significance level.

b) Analysis of Variance in Skill Distributions (Profiles)

Apart from the sources of variance, this more detailed table shows

Degrees of Freedom - D.F.
Sums of Squares - S.S.
Mean Squares - M.S.
and Variance Ratio - V.R.

Skill levels are denoted by SL, technology levels by T and firms by F.

Improved estimate of residual variance was obtained by pooling the sums of squares and the degrees of freedom of the original residual estimate and of the T x F interaction. The mean squares of the SL x T and SL x F interactions and of the main effects were tested against this improved estimate.

Technology	Mean Skill Level	σ^2	Rise in Mean Skill Level	t	D.F.	Significance Level
Manual	280.5	3806.9	42.4	4.63	204	$P < .001$
Computerized	322.9	4212.0				
Semi-Automatic	251.5	8247.8	9.9	1.03	344	Not Significant
Computerized	261.4	7520.5				

TABLE F-2: STATISTICAL DATA FOR TESTING DIFFERENCE BETWEEN MEAN SKILL LEVELS AT EACH TECHNOLOGICAL LEVEL.

Skill Level	Technology 1		Technology 2	
	Firm 1 (N1)	Firm 1 (P1)	Firm 2 (N2)	Firm 2 (P2)
Low	6.4	35.0	0.6	22.3
Medium	87.5	85.2	37.9	57.4
High	33.1	79.0	39.7	66.5
Totals	127.0	199.2	78.2	146.2

TABLE F-3: MANHOURS PER UNIT CLASSIFIED BY SKILL LEVEL, FIRM, AND TECHNOLOGY.

Source of Variance	D.F.	S.S.	M.S.	V.R.	Significance Level
Between Skill Levels	2	5640.06	2820.03	35.82	$P < .01$
Between Technologies	1	863.60	863.60	10.97	$P < .05$
Between Firms	1	1638.00	1638.00	20.81	$P < .025$
SL × T	2	726.64	364.32	4.63	
SL × F	2	375.55	187.78	2.39	
T × F	1	0.54	0.54		
Residual	2	235.64	117.82		
Improved Residual Estimates	3	236.18	78.73		
Total	11	9482.03			

TABLE F-4: ANALYSIS OF VARIANCE SUMMARY

APPENDIX G

COMPARISON OF SKILL LEVELS ACROSS PROCESS TYPES

1. DEVELOPMENT OF INDIVIDUAL SKILL SCALE GROUPINGS

As explained earlier, the skill point scores for the jobs in each process were determined with reference to the job evaluation scheme used in the corresponding company or industry. Since the schemes differed, the peculiarities of each had to be taken into account when grouping skill scores into the six or seven levels making up the skill profiles, and shown in the tables and figures in the chapters describing the individual processes. As far as possible equal groupings were used, but this could not always be done due to gaps and discontinuities in the sequence of skill scores in some of the job evaluation schemes. The further condensation of skill levels into the low, medium, and high skill categories used in Chapter 8 was accomplished by grouping two or three adjacent levels depending upon the characteristics of the distributions.

2. COMPARISON OF INDIVIDUAL SKILL SCALES

The comparability of the different skill scales of each process was evaluated in two ways. First, the break points between low and medium, and between medium and high skill groups were analyzed to determine if they are consistent across scales. This was done by subjectively matching jobs from each process with skill scores falling on both sides of the break points. Secondly, jobs roughly midway between the break points were compared to establish the homogeneity of each of the low- medium- and high-skill categories across the processes studied. The titles used for these purposes and their positions on the respective scales are shown in Figure G1, followed by the corresponding job descriptions.

3. CONCLUSIONS

From a comparison of the job content, and particularly the assessment of the amount of discretion allowed job holders close to each breakpoint it appears that the breakpoints do indeed fall roughly in the same place across all the several skill-scales. The same also applies to the mid-category jobs. Thus a score on one scale broadly represents the same degree of skill as the corresponding score on another scale. More specifically, the low skill positions require the job holder to follow simple, closely prescribed procedures occuring in routine sequence. Jobs in the medium skill range, though they too call for the execution of fairly simple procedures, also involve some selection between these procedures to accommodate some variations in demand. The nature of the demands and to some extent the timing of their occurrence are however largely predictable. Finally, job holders in the high skill class must be capable of coping with unpredictable demands, using procedures not fully specified in advance. The Utilityman (steel), the Paying and Filing Clerk (bank), and the Group Sales Agent (passenger reservations) positions are respective examples of these three types of job demand.

4. DESCRIPTION OF JOBS NEAR BREAKPOINTS

Low Skill/Medium Skill Breakpoint

Steel

Oil-Greaser (1.4)--Lubricates equipment as directed, scheduled, or specified on check off lists and charts; selects proper equipment to perform the job. Replaces broken fittings, using easy-out, wrenches, etc. Cleans plugged fittings with wire. Cleans off dirty fittings prior to lubricating. Operates mill machinery when necessary to work in lubricants and check levels and pressures. Inspects equipment for proper maintenance of oil or hydraulic fluid levels, adding oil or fluid as required to maintain levels, inspects to prevent damage to machinery due to overheating, high bearing temperatures, etc. Changes oil and hydraulic fluid in equipment as directed. Following established procedures, sets up proper method for cooling hot bearings. Adjusts oil flow on pinions, bearings, etc. Has recourse to Foreman or Millwright on problems deviating from normal routine.

Assorter Helper (1.5)--Assists catcher to turn over, inspect, stencil, sort and pile sheets at exit-end of galvanizing line.

Bank

Messenger-Clerk (88)--Maintains, issues and controls branch supplies. Delivers mail, clearing, supplies and various other items for the branch. Acts as safe deposit custodian.

Statement Cycling Clerk (92)--Prepares cycle statements for delivery or mailing to branch customers. Delivers statements to customers, answers telephone inquiries regarding account status, placing of holds or stop payments or customer complaints. Pays and files checks processed through EDP. Operates NCR or IBM proof machine as necessary. Prepares record changes and various reports for the EDP Center. Receives and prepares checkbook and deposit slip orders. Photographs deposit slips and all outgoing clearings.

Machining

Filer and Burrer-Machined Parts (455)--Performs such operations as removing burrs, sharp edges and scratches and performs other filing and grinding operations on machined parts, such as grinding, fairing in and blending radii, chamfering, etc., where moderate tolerances are involved. Improvises temporary tooling such as holding fixtures required in the set-up and operation of burring equipment, such as grinders, drill presses, etc. Selects, dresses and trues own abrasive wheels. Maintains good shop practice.

Passenger Reservations

Clerk (145)--Answers telephone calls and provides information regarding arrival and departure times, specific passenger inquiries and general information inquiries. Teletypes messages to central reservations control and to downline offices. Updates arrival and departure board.

Records Clerk (165)--Maintains manuals, records materials and files. Prepares and maintains routine and moderately complex records, reports, forms and similar material. Obtains and compiles data for reports. Tabulates, posts and checks calculations. Types routine letters, forms and other materials. Performs general clerical duties including sorting and distributing mail and answering telephone and routing requests for information. Takes and transcribes dictation as required.

Oil Refining

No jobs at this level.

Electricity Generation

Oiler (180)--Operates auxiliary equipment, including pumps, condensers, oil filters, etc., and lubricates equipment. Assists other operating personnel as required, does necessary cleaning and performs minor maintenance work of a preventive or cleaning nature.

Air Separation

Operator (160)--Monitors operations in the computer controlled plant to the extent of identifying error messages typed out on the remote teletypewriters located in his work area; calls for maintenance or supervisory personnel whenever necessary.

Medium Skill/High Skill Breakpoint

Steel

Annealing Line Coiler (3.2)--Shears the strip and operates controls to discharge coils from line. Starts new coils in re-coiler, trims coils and tack welds coil identity disks. Observes finished strip for oxide discoloration or oil from reels, and for scratches. Assists in starting up and shutting down line and on adjustments and breakdowns. Obtains Rockwell test samples. Performs tractor work as required. Compiles production, delay, and special study reports.

Scheduler-Annealing (3.3)--Preplans weekly operation of annealing line. Using Operating Standard Practices, develops and issues daily comedown schedules. Supplies order service information to finishing departments and maintains necessary records and reports.

Extra Craneman (3.6)--Fills in working time getting tools and supplies for Electricians and performing miscellaneous duties in shop until called out to operate any crane in mills requiring operator. Picks up lifts of materials or equipment as directed; transports, positions, and places them wherever required. Lubricates crane used as necessary. Inspects cables and brakes.

Bank

Secretary (126)--Takes and transcribes dictation from EDP Center manager and his assistants. Maintains clerical control of personnel and operation records, and performs various duties pertinent to the administration of the EDP Center manager's functions.

New Accounts Teller A (129)--Opens new checking, savings and special purpose accounts for individuals, corporations, and organizations. Prepares and mails form to reference bank. Orders checks, deposit tickets, and endorsement stamps. Bills customers' or charges account when necessary. Reconciles branch records to monthly bill from printer and prepares entries to proper accounts. Answers customers inquiries. Accepts commercial and savings deposits. Pays savings withdrawals and cashes checks. Receives requests for signature changes on commercial accounts. Receives request for and delivers statements to customers. Transfers cash received to teller and obtains receipt or balances daily cash, and transfers excess to Vault Teller.

Audit Clerk C (136)--Maintains records; has custody of reserve supply of numbered forms and supplies them to departments upon request. Maintains control of vault supply of traveler's checks. Maintains furniture and equipment inventory control. Issues cashier's check in payment of bills incurred by branch. Searches branch records for information requested by authorized government agents. Assists in listing and balancing proofs, counts errors and makes adjustments on the accounts, services complaints and charges over teller's cashing limit. Relieves as Note Teller, New Accounts Teller, General Ledger Bookkeeper, Reconcilement Clerk, Supply Clerk, etc. Posts cash control records and compiles cash control reports. Types revised lists of dormant accounts and posts dormant charges. Reviews inactive commercial ledgers. Calculates or checks calculations of overtime pay due staff. Semi-annually calculates inter-branch expense and note charges. Annually searches for records for bank inspectors and answers queries.

Machining

Duplicating and Profiling Machine Operator (576)--Sets up duplicating and profiling machines to reproduce parts where materials and tooling are provided and machining methods, operation sequences and tolerances have been predetermined. Mounts, fastens and aligns model, pattern or template. Selects and adjusts cutter and tracer, sets speeds, feeds and depth of cut. Scribes reference points and lines as a guide for aligning work with patterns, model or template. Operates automatic duplicating machines, such as Keller, Hydro-Tel or Trutrace equipped machines and manually operated duplicating machines.

Passenger Reservations

Baggage Representative (290)--Obtains, from passenger, information concerning baggage complaints (lost, damaged, mishandled baggage) and makes on-the-spot adjustments for minor claims.

Group Sales Agent (313)--Reserves and confirms blocks of seats for entire itineraries of organized groups of 10 or more passengers travelling together. Processes individual reservations of group passengers as required. Follows progress of group bookings to determine reduced or increased seat requirements. Notifies reservations control of group status and provides listing of services required at each point of itinerary. Maintains complete record of information for each group.

Oil Refining

No jobs at this level.

Electricity Generation

Electrician (350)--Tests and locates electrical faults. Dismantles, inspects and repairs generators, condensers, motors, oil circuit breakers and similar equipment. Works from blueprints to install conduit, pull in conduit, make corrections, and install and replace wiring on control switchboard panels.

Welder-Steam (378)--Builds up and welds metal parts by means of oxyacetylene or electrical welding apparatus. Fabricates metals and repairs cracked and broken parts of turbines, boilers, superheaters, and other high pressure vessels.

Air Separation

Maintenance Mechanic (280)--Performs routine and emergency maintenance work on the units (excluding control and recording instrumentation) as requested by Foreman or Operator. Provides assistance and intermittent work direction to Maintenance Helper.

5. DESCRIPTION OF MIDRANGE JOBS

Low Skill

Steel

Utility Man (1.0)--Assists crane man in the performance of his duties and hooks, unhooks and positions material and equipment transported by cranes in annealing department. Inspects inner covers on furnace bases after furnace is removed to detect leaks.

Bank

No jobs at this level.

Machining

Factory Helper General (396)--Assists in handling and positioning heavy materials and equipment, securing tool for set-up, helping in breaking down the set-ups, segregating tools and fixtures and returning to proper sources. Loads and unloads parts on and off machines. Removes scrap, shavings, chips from the machines and helps in keeping work areas, machines and equipment clean and in orderly condition. Numbers or hand-stamps parts for identification, cleans and lubricates parts, de-burrs, sands, putties, masks and hand-stencils.

Passenger Reservations

Ticket Preparation Agent (103)--Computes or has computed fares for each ticket recquisition received. Prepares cash slip invoice for tele-ticketing form as necessary, and fills out ticket. Maintains a log of all tickets issued.

Oil Refining

No jobs at this level.

Electricity Generation

Shift Helper (96)--Assists any of the shift personnel as directed. Among other things may be required to assist the employee in charge of the operation in blowing soot and changing boiler fuels. He may also be required to check the operation of the evaporators, take various readings, do necessary cleaning and perform minor maintenance work of a preventive or cleaning nature.

Air Separation

No jobs at this level.

Medium Skill

Steel

Welding Machine Operator (2.5)--Operates equipment to feed and weld coils at entry end of electrolytic cleaning line. Assists in operating controls and adjusting equipment. Participates in repairing strip breaks, threading line, removing twists and cobbles and placing scrap in containers.

Bank

Paying and Filing Clerk B (105)--Pays and files posted debits and credits received from EDP Center. Receives and processes commercial statements for mailing or delivery to customers. Answers telephone inquiries regarding account status, placing of holds, stop payments or customer complaints. Assists customers in reconcilement of statements. Receives and prepares check and deposit slip orders.

Machining

Hand Finisher-Precision-B (525)--Performs close tolerance hand finishing operations on machined parts, assemblies and weldments involving various radii, contours, angles, flanges, etc. Removes material by precision grinding, filing, and blending prior to final finishing. Performs final finishing where adequate tooling is provided. Selects, dresses and trues own abrasives. Checks own work for conformance to specifications. Maintains good shop practice. Assists Hand Finisher-Precision A, as required.

Passenger Reservations

Secretary (231)--Takes dictation and prepares correspondence; types reports, prepares records and processes routine documents. Answers phone, makes appointments, and opens and prepares mail.

Oil Refining

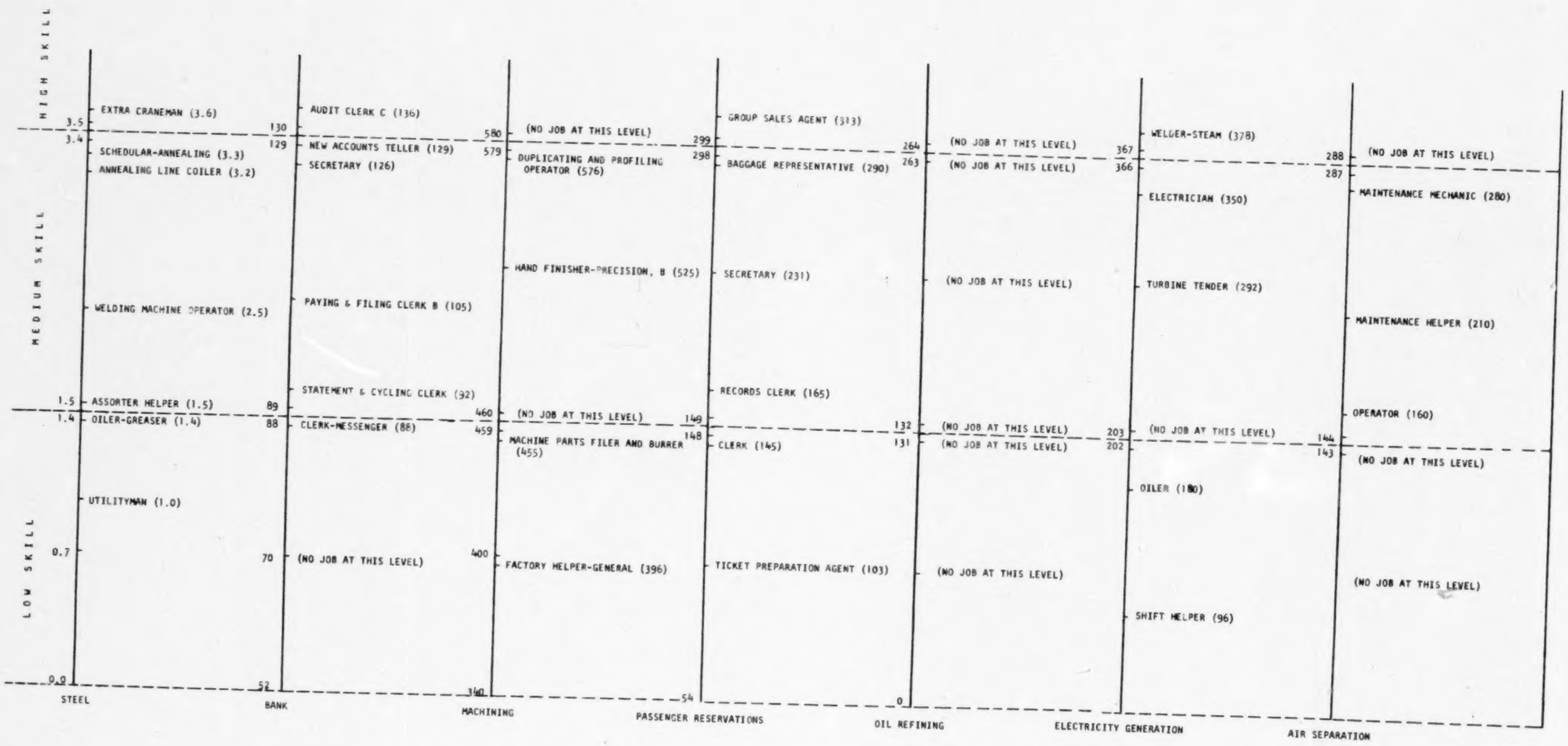
No jobs at this level.

Electricity Generation

Turbine Tender (292)--Starts, stops and tends the operation of high pressure steam turbines and miscellaneous auxiliary equipment under the direction of the Shift Foreman, including all prescribed checking procedures for the particular plant. Also is required to oil, grease, and do necessary cleaning around the turbine and related equipment.

Air Separation

Maintenance Helper (210)--Assists Maintenance Mechanic in routine and emergency maintenance work.


HIGH SKILL
MEDIUM SKILL
LOW SKILL
3.5
3.4
1.5
1.4
0.7
0.0
EXTRA CRANEMAN (3.6)
SCHEDULAR-ANNEALING (3.3)
ANNEALING LINE COILER (3.2)
WELDING MACHINE OPERATOR (2.5)
ASSORTER HELPER (1.5)
OILER-GREASER (1.4)
UTILITYMAN (1.0)
STEEL
130
129
89
88
70
52
AUDIT CLERK C (136)
NEW ACCOUNTS TELLER (129)
SECRETARY (126)
PAYING & FILING CLERK B (105)
STATEMENT & CYCLING CLERK (92)
CLERK-MESSENGER (88)
(NO JOB AT THIS LEVEL)
BANK
580
579
460
459
400
340
(NO JOB AT THIS LEVEL)
DUPLICATING AND PROFILING OPERATOR (576)
HAND FINISHER-PRECISION, B (525)
(NO JOB AT THIS LEVEL)
MACHINE PARTS FILER AND BURRER (455)
FACTORY HELPER-GENERAL (396)
MACHINING
299
298
149
148
54
GROUP SALES AGENT (313)
BAGGAGE REPRESENTATIVE (290)
SECRETARY (231)
RECORDS CLERK (165)
CLERK (145)
TICKET PREPARATION AGENT (103)
PASSENGER RESERVATIONS
264
263
132
131
0
(NO JOB AT THIS LEVEL)
(NO JOB AT THIS LEVEL)
(NO JOB AT THIS LEVEL)
(NO JOB AT THIS LEVEL)
(NO JOB AT THIS LEVEL)
(NO JOB AT THIS LEVEL)
OIL REFINING
367
366
203
202
WELDER-STEAM (378)
ELECTRICIAN (350)
TURBINE TENDER (292)
(NO JOB AT THIS LEVEL)
OILER (1[illegible]0)
SHIFT HELPER (96)
ELECTRICITY GENERATION
288
287
144
143
(NO JOB AT THIS LEVEL)
MAINTENANCE MECHANIC (280)
MAINTENANCE HELPER (210)
OPERATOR (160)
(NO JOB AT THIS LEVEL)
(NO JOB AT THIS LEVEL)
AIR SEPARATION

APPENDIX H

LABOR-ELASTICITY OF VARIOUS INDUSTRIES AROUND 1960

TABLE H-1: LABOR-ELASTICITY OF VARIOUS INDUSTRIES AROUND 1960

Industry	Production				ΔP/P %	Employment		ΔE/E %	Mean Levels		Elasticity Coefficient $\frac{\Delta E/\bar{E}}{\Delta P/\bar{P}}$	Classification
	High	Year	Low	Year		High	Low		$\bar{P}$	$\bar{E}$		
Copper Ore Mining (SIC 102)	113	1956	90	1959	22.7	33 k	33k	39.3	101.5	28.5k	1.73	E(?)
Bituminous Coal Mining (SIC 12)	115	1956	93	1958	21.2	220 k	190k	14.6	104	205 k	0.69	ME
Crude Petroleum (SIC 13)	102	1956	97	1958	5	335 k	325k	3	99.5	330 k	0.61	ME
Contract Construction (SIC 15, 16, 17)	-	-	-	-	-	-	-	-	-	2900 k	-	-
Lumber and Wood Products (SIC 24)	108	1959	96	1958	11.8	670 k	630k	6.2	102	650 k	0.53	ME
Furniture and Fixtures (SIC 25)	-	-	-	-	-	-	-	-	-	370 k	-	-
Glass Containers (SIC 3221)	100	1957	97	1958	3	55 k	56k	- 0.5	98.5	55 k	-0.16	L
Hydraulic Cement (SIC 324)	102	1956	93	1957	5.1	42 k	42k	0	97.5	42 k	0	L
Concrete, Gypsum and Plaster (SIC 327)	114	1959	96	1958	17.1	160 k	140k	14.0	105	150 k	0.76	E
Iron and Steel (SIC 331)	98	1959	86	1958	13	590 k	610k	- 3.3	92	600 k	-0.25	L
Foundry - Iron and Steel (SIC 332, 336)	104	1959	87	1958	17.8	212 k	192k	9.9	95.5	202 k	0.56	ME
Foundry - Non-Ferrous (SIC 332, 336)	104	1959	87	1958	17.8	67.5k	60k	11.8	95.5	63.8k	0.66	ME
Primary Aluminum (SIC 3334, 3352)	106	1960	91	1958	15.2	70 k	64k	8.9	98.5	67 k	0.59	ME
Electric Machinery (SIC 36)	116	1961	90	1958	25.2	1450 k	1200k	18.9	103	1325 k	0.75	E
Motor Vehicles (SIC 371)	7.8M	1960	6.8M	1961	13.7	725 k	625k	14.8	7.3M	675 k	1.08	E
Aerospace (SIC 372, 192)	-	-	-	-	-	-	-	-	-	780 k	-	-
Instruments (SIC 38)	118	1960	92	1958	24.8	345 k	325k	6	105	335 k	0.24	L
Meat Products (SIC 201)	107	1960	96	1958	9	320 k	320k	0	102	320 k	0	L
Dairy Products (SIC 202)	111	1962	103	1959	7.5	325 k	330k	- 1.5	107	328 k	-0.20	L
Flour and Other Grain Mill Products (SIC 2041)	107	1963	104	1959	4.3	23 k	27k	- 1.6	105.5	25 k	-0.37	L
Bakery Products (SIC 2051, 2052)	-	-	-	-	-	-	-	-	-	300 k	negative	L(?)
Malt Liquors (SIC 2082)	-	-	-	-	-	-	-	-	-	70 k	negative	L(?)
Tobacco Products (SIC 211, 212, 213)	-	-	-	-	-	-	-	-	-	40 k	negative	L(?)
Textile Mill Products (SIC 22)	107	1959	94	1958	12.9	870 k	855k	1.7	100.5	862.5k	0.13	L
Apparel (SIC 23)	108	1959	95	1958	12.8	1230 k	1175k	4.6	101.5	1202.5k	0.36	ML
Pulp, Paper, and Board (SIC 261, 262, 263, 266)	-	-	-	-	-	-	-	-	-	230 k	-	L(?)
Printing and Publishing (SIC 27)	118	1963	95	1958	21.6	960 k	890k	7.5	106.5	925 k	0.35	ML
Synthetic Materials and Plastics (SIC 282, 3079)	190	1963	135	1961	33.8	175 k	155k	12.1	162.5	165 k	0.36	ML
Petroleum Refining (SIC 291)	-	-	-	-	-	-	-	-	-	120 k	negative	L(?)
Tires and Inner Tubes (SIC 301)	110	1959	91	1958	19	93 k	87k	6.7	100.5	90 k	0.35	ML
Footwear - Except Rubber (SIC 314)	105	1959	96	1958	11	235 k	225k	4.3	100.5	230 k	0.39	ML
Railroads (SIC 401)	-	-	-	-	-	-	-	-	-	700 k	negative	L(?)
Motor Freight (SIC 42)	113	1959	95	1958	18	840 k	780k	7.4	104	810 k	0.41	ML
Water Transportation (SIC 44)	-	-	-	-	-	-	-	-	-	230 k	-	L(?)
Air Transportation (SIC 452)	7.1TM	1963	6.3TM	1962	11.9	180 k	170k	5.7	6.7	175 k	0.56	ME
Telephone Communication (SIC 481)	-	-	-	-	-	-	-	-	-	680 k	-	L(?)
Electric Power and Gas (SIC 491, 492, 493)	-	-	-	-	-	-	-	-	-	570 k	-	L(?)
Wholesale and Retail Trade (SIC 50, 52-59)	-	-	-	-	-	-	-	-	-	11800 k	-	-
Banking (SIC 60)	4.1B	1963	3.4B	1960	18.7	750 k	680k	9.8	3.75B	715 k	0.52	ME
Insurance Carriers (SIC 63)	-	-	-	-	-	-	-	-	-	870 k	-	-
Federal Government (SIC 91)	-	-	-	-	-	-	-	-	-	2300 k	-	-

SOURCE: Bureau of Labor Statistics Report #1474, Technological Changes in Major American Industries, 1963.

PROCEDURE: Adjacent high and low production years and levels were identified from graphs (Columns 2-5). The differences ΔP between high and low were divided by mean production (Column 10) and entered in Column 6. Employment levels for the same years yielded ΔE (Column 12), and hence ΔE/E (Column 9). The quotient of these yielded the elasticity coefficient ΔE/E / ΔP/P (Column 13). Industries were classified as follows:

E = Elastic Coefficient ≥ 0.75
ME = Moderately Elastic 0.50 - 0.74
L = Laborstatic ≤ 0.24
ML = Moderately Laborstatic 0.25 - 0.49